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BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA

Order Instituting Rulemaking to consider policy and implementation refinements to the Energy Storage Procurement Framework and Design Program (D.13-10-040, D.14-10-045) and related Action Plan of the California Energy Storage Roadmap.	R.15-03-011 Filed March 26, 2015

COMMENTS OF EDF RENEWABLE ENERGY, INC. ON ASSIGNED COMMISSIONER AND ADMINISTRATIVE LAW JUDGE'S SCOPING MEMO AND RULING SEEKING PARTY COMMENTS

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February 5, 2016

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In accordance with the Rules of Practice and Procedure of the California Public Utilities Commission ("Commission"), EDF Renewable Energy, Inc. ("EDF RE") hereby submits these comments on the *Assigned Commissioner and Administrative Law Judge's Scoping Memo and Ruling Seeking Party Comments* issued by Assigned Administrative Law Judge Julie M. Halligan and Assigned Commissioner Carla J. Peterman on January 15, 2016 ("Scoping Memo").

I. DESCRIPTION OF EDF RENEWABLE ENERGY, INC.

Headquartered in San Diego and directly employing over 500 Californians, EDF RE is a national developer, owner and operator of energy storage, wind, solar, biomass, and biogas resources. To date, EDF RE has developed over 6,700 megawatts ("MW") of renewable energy projects in North America, including wind, solar and biogas projects located in California and/or serving California customers. EDF RE is developing a 394 MW pumped hydro storage project known as "Swan Lake North" in southern Oregon to serve California that is described in Appendix A attached to these comments.

II. INTRODUCTION.

EDF RE appreciates the opportunity to respond to two specific questions in the Scoping Memo, Question Numbers 1(b) and 2(a) set forth in Section 15 of the Scoping Memo. The body of analysis regarding pumped storage's cost-effectiveness and important role in providing flexibility and reliability to the grid has continued to grow over many years. With a state electricity portfolio that increases to 50% renewable energy and a focus on minimizing carbon emissions, the Commission should expedite its analysis by its own staff to determine need and to authorize procurement of a new pumped storage project to come on-line after 2020.

The existing procurement process does not include pumped storage above 50 MW in the Energy Storage Framework and Program of 1.3 Gigawatts ("GW") established by the Commission pursuant to AB 2514 ("ESP Framework").[1] Therefore, EDF RE recommends that a separate procurement process should be conducted, due to significant differences in storage project scale and lead time. Pumped storage's high net benefit value, its high viability given global commercial development experience, and its multi-year development lead time, require that the Commission not delay procurement authorization of pumped storage very many years into the future or risk foregoing pumped storage's grid benefits to the detriment of California's ratepayers.

EDF RE advocates that the Commission should convene a multi-stakeholder process to identify a competitive procurement program, with design elements that will ensure appropriate

[1] *Decision Adopting Energy Storage Procurement Framework and Design Program*, D.13-10-040, issued October 17, 2013.

cost allocation and project viability for development of pumped storage.[2] Recent analysis points to the need for more energy storage resources overall early in the next decade with a role for multiple technologies and to a strong net benefit value for ratepayers from new pumped storage projects.[3]

III. THE COMMISSION SHOULD ADOPT ENERGY STORAGE PROCUREMENT TARGETS BEYOOND 2020 AT THIS TIME.

EDF RE responds first to Question 1(b) posed in the Scoping Memo:

> **Considering the directive in *Senate Bill 350 (De Leon, 2015)* to develop an Integrated Resource Planning Process, should the Commission adopt ESP targets beyond 2020 at this time? If so, what factors should the Commission consider in adopting future targets, and what is an appropriate target?**

EDF RE briefly notes that pumped storage sized greater than 50 MW was excluded from the AB 2514 procurement target, not due to a finding of a lack of need, but rather because it was simply deemed too large to fit within the Commission's determination and would "inhibit the fulfillment of market transformation goals."[4] The question in going beyond the current 1.3 GW program size is whether more capacity should be added based on need or whether the "market transformation" criterion is still paramount. EDF RE sees a strong case for the former alternative, given that establishment of the ESP Framework itself is already clearly in the process of transforming the energy storage market. Further, enactment of Senate Bill 350 ("SB 350")

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[2] The viability requirement serves in great part to address any reasonable concerns about environmental permitting, construction risk, and the longer construction lead time. Those risks are borne by the developer, not the ratepayer, and should not be seen as a barrier to thoughtful work going forward at the Commission regarding pumped storage procurement. As to sharing risk and rewards, many terms in the existing SCE *pro forma* energy storage contract are useful for a future pumped storage contract.

[3] As discussed in these comments substantial analytical work in the private, academic, and government sectors all point in essentially the same direction.

[4] D.13-10-040, at p. 34.

has essentially confirmed the real-world relevance of the legislative imperative of AB 2514, which was for energy storage to provide reliability, minimal carbon emissions, and flexibility in light of potential high renewable resource penetration.

How need is determined will include a variety of tools available to provide reliability, minimize cost and accommodate high renewables penetration while solving for greenhouse gas ("GHG") emission reduction. The recent Commission staff white paper on grid reliability identifies numerous tools that have been discussed elsewhere, including more regional integration of grid operations, use of renewables' reliability "by-products", transmission expansion, distributed resources, demand response, and energy storage.[5]

Analysis by the Union of Concerned Scientists ("UCS") and the Low-Carbon Grid Study both incorporate some level of improved regional integration in addition to some or all of the tools available to the Commission.[6] Both studies examine a future with 50% renewables serving California. In the case of UCS's study, exporting 1 GW of renewables from the state parallels the need to draw on renewables' flexibility and reliability attributes, 1 GW of demand response, and 1 GW of new energy storage beyond the existing ESP target. The UCS study does not specify pumped storage among energy storage technologies, but very clearly points to the overall need for energy storage.

The Low-Carbon Grid Study includes 1 GW of new pumped storage which contributes alongside all of the foregoing measures, including full implementation of the existing 1.3 GW

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[5] *Beyond 33% Renewables: Grid Integration Policy for a Low-Carbon Future*, Commission Energy Division, November 25, 2015.

[6] *Achieving 50 Percent Renewable Electricity in California: The Role of Non-Fossil Flexibility in a Cleaner Grid*, Union of Concerned Scientists, August 2015; *Low Carbon Grid Study: Analysis of a 50% Emission Reduction in California*, National Renewable Energy Laboratory and Center for Energy Efficiency and Renewable Technologies, January 2016.

ESP target plus 1.5 GW of additional battery storage and 1.2 GW of new compressed air storage. The new pumped storage, inputs of which are based on real-world data, proves to be an important component alongside the other measures to ensure net rate benefits, significant GHG emission reductions, and renewables penetration above 50%, plus higher penetration of distributed solar generation.

Recent statements by the California Independent System Operator ("CAISO")[7] and independent analysis by EDF RE and other pumped storage developers all point in different but similar ways to the value of pumped storage in a 50% renewables world. We discuss the CAISO's statements and EDF RE's analysis in our response to the Commission's Question Number 2(a) below.

A. <u>There is a Need for Transparent, Comprehensive Analysis of Pumped Storage.</u>

There should be an analysis from the Commission that confirms need, rather than merely relying upon the studies mentioned above (and discussed further below). EDF RE understands that SB 350 directs a comprehensive integrated resource planning ("IRP") process at the Commission to determine what a comprehensive electricity resource portfolio should look like. This approach is rational given the numerous industries advocating for procurement and the many options available to accommodate high renewables penetration while solving for GHG emission reduction, cost-effectiveness and reliability. However, no party, including EDF RE, can know the length of time required to complete such analysis by the Commission.[8]

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[7] *See, e.g.*, CEO Report to CAISO Board of Governors, December 15, 2015, "Storage will have to become a larger part of the resource mix. It provides the opportunity to shift both demand and generation and could be a significant game changer."

[8] The Agenda for the Commission's Business Meeting on February 11, 2016, includes a reference to a new *Order Instituting Rulemaking to Develop and Electricity Integrated Resource Planning Framework and to Coordinate and Refine Long-Term Procurement Planning Requirements.*

In the case of pumped storage, the long lead time inherent in a major project is particularly vulnerable to a deferral of procurement authorization well into the future in the context of an IRP process that requires several years to complete. The challenges discussed extensively by CAISO regarding 2024 renewable curtailment point to the need for decisions that can bring solutions online by that time.[9] For pumped storage to be an effective part of that solution, construction requires a five- to six-year lead time.

While a longer construction lead time does not mean that procurement authorization needs to occur today in order for a project to come on line early next decade, it does mean that there needs to be a clear decision to fully incorporate pumped storage equally alongside other "flexibility options" with a clear timeline going forward as to when a determination will be made one way or another - certainly within the next two years.

Hence, over the next six months, the Commission should complete an analysis of the total net benefit of pumped storage that incorporates other "flexibility options" as discussed above. The analysis would be a part of the record in this proceeding, and inform the Commission's 2014 Long-Term Procurement Plan ("LTPP") proceeding, and/or a future IRP-oriented Commission proceeding.[10] The creation of an effective modelling methodology, inputs, and assumptions should be transparent with full consultation by experts in pumped storage technology and operations.

In determining the potential need for new energy storage resources, we also believe that the issue of properly valuing the many reliability- and cost-related benefits of energy storage is

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[9] *See, e.g., California Independent System Operator Corporation Deterministic Studies*, filed with the Commission on May 8, 2015.

[10] R.13-02-010; *and see* footnote number 8, *infra*.

no different for pumped storage than it is for other storage technologies. Therefore, efforts to value energy storage's attributes can encompass both pumped storage and other energy storage technologies, noting that pumped storage has the capability to provide longer "regulation up" and "regulation down" ancillary services.

There is no need for two separate efforts focused on pumped storage and other energy storage technologies within the current ESP Framework to properly value pumped storage's many valuable attributes. Rather, efforts to properly value energy storage in general should encompass pumped storage, with the much longer energy discharge capabilities of pumped storage taken into account in the analysis.

B. Proposed Procurement Approach

While pumped storage above 50 MW need not be included within the existing ESP Framework, the Commission should consider adding more demand to the existing ESP Framework and using only those resources, as one track, or phase, of ongoing AB 2514 implementation. The UCS study points to the need for 1 GW of new energy storage. In the case of Swan Lake North, the additional 1 GW can include both new pumped storage (in Swan Lake North's case 394 MW) plus far more energy storage that currently qualifies for the ESP target. In short, there is likely a need for many energy storage resources with new pumped storage not precluding more opportunity for other technologies.

However, inclusion of pumped storage in the current ESP Framework would not reflect the scale, lead time, and location characteristics of pumped storage. The current ESP Framework entails procurement of resources within each of the three investor owned utility ("IOU") service territories. It also requires projects to come on line well within pumped storage's necessary lead time. Further, procurement is scaled annually at levels within each IOU's territory at capacities typically below that of a single pumped storage project. Finally, there are widespread system benefits among all of California's IOUs suggesting strongly that a multi-IOU procurement approach is most appropriate.

Separate procurement by individual IOUs, as occurs in the current ESP Framework, would require a potentially unrealistic combination of decisions that could lead to a full subscription for a single, financeable pumped storage project. Hence there needs to be a fully coordinated, multi-IOU procurement process. Only the Commission can convene or require such a process among multiple IOUs. It is too early and perhaps not even appropriate to propose the details of such a process given its novelty, without the full input of the potential users of the pumped storage resource, the Commission, and stakeholders.

At this point EDF RE proposes only the following foundational elements of a workable procurement process for pumped storage:

- **Competition**. There should be competitive procurement among pumped storage projects in development. Holding a FERC license should not be the sole criterion for eligibility, provided viability controls are in place to which the developer is willing to attest.
- **Cost Allocation**. Cost allocation should be flexible based on relative net benefits among participating IOUs. The location of a pumped storage project influences the value the project delivers to multiple IOUs, with closer proximity resulting in higher benefits. In the context of a competitive procurement among multiple potential pumped storage projects to serve the state, there needs to be consideration of and flexibility regarding the allocation of costs dependent upon the actual pumped storage project or projects selected.

- **Viability controls including bid evaluation and financial commitment by the developer**. The longer lead time of pumped storage would make project failure several years into the future a particularly costly failure, as selection of a project would likely lead other projects to stop work. In other words, failure of a project prior to completion is not easily replaced by foregone projects. During the bid evaluation process, viability analyses should include site-specific considerations, developer-based financial viability and technology viability. During the contracting process, the developer should commit to providing a letter of credit associated with hitting milestones for on-line delivery. Non-refundable deposits covering the life of the construction of the project can also serve to incentivize the bidding of viable projects with credible development timelines.
- **Use of existing energy storage *pro forma* contracts from the current ESP Framework**. This would entail review of existing energy storage *pro forma* contracts to determine what is transferrable to a pumped storage procurement contract.

We note that each the above highlighted elements for viability serve in part to address any vague concerns about environmental permitting, construction risk, and longer construction lead time. Those risks are borne by the developer, not the ratepayer, and should not serve to block thoughtful work going forward at the Commission regarding pumped storage procurement.

There are tools and themes in common between the current ESP procurement approach and a future pumped storage procurement. An initial review of Southern California Edison's *pro forma* contract developed as a product of the existing ESP Framework demonstrates that there are many elements that are transferrable to pumped storage procurement. In fact, there are a variety of "off-the-shelf" tools already approved by the Commission within the current ESP Framework that can be readily transferred to pumped storage procurement. The Commission need not reinvent the entire wheel, so to speak, on these fronts for pumped storage.

IV. THE COMMISSION SHOULD REVISIT PREVIOUSLY EXCLUDED PUMPED STORAGE PROJECTS SIZED GREATER THAN 50 MW.

EDF RE responds next to Question 2(a) posed in the Scoping Memo:

> **What new information and/or evolving circumstances exist such that the Commission should revisit previously excluded energy storage technologies, such as controlled electric vehicle charging or pumped storage projects greater than 50 MW? The Commission will not consider comments that simply restate positions previously offered and addressed in D.14-10-045.**

A. Enactment of SB 350 Has Heightened The Need to Implement Flexibility Measures to Optimize For Reliability, Cost and Carbon.

The most obvious development since the Commission's decision to create the current ESP Framework (D.13-10-040) is the enactment of SB 350. The legislation has essentially codified the state's movement to a renewable energy future and a low-carbon electricity system that in turn heightens the imperatives of AB 2514 - namely, for energy storage to enable high renewable energy penetration, carbon minimization, and ratepayer cost benefits. As discussed above, SB 350 points to a focus on resource need. That need in turn points to the importance of project viability, cost, and value for a new electricity system.

EDF RE believes that focus on need should require the Commission to revisit its exclusion of pumped storage technologies from the "market transformation" procurement authorization under AB 2514 and to pivot to need based on technology value for a transformed system. As also discussed above, this entails further analysis of flexibility options, and particularly analysis of previously excluded technologies such as pumped storage.

B. The CAISO Has Called for Increased Emphasis on Pumped Storage as a Solution to Future Overgeneration and Ramping Issues

On July 22, 2015, the CAISO filed an *ex parte* communication notice in this proceeding specifically addressing pumped storage.[11] The communication directly addressed the question of "whether new information and/or evolving circumstances exist such that the Commission should revisit previously excluded energy storage technologies such as vehicle-grid integration and pumped hydro storage." The *ex parte* notice attached a July 21, 2015, letter from the CAISO's Chief Executive Officer, Steven Berberich, that states, "the ISO has identified over-generation and ramping concerns associated with increased renewable generation." Accordingly, he further states:

> "energy storage…has the potential to be a cornerstone of the new electric network. Pumped energy storage, in particular, can be constructed at large scale, with characteristics that are necessary to meet our grid's over-generation and ramping needs. The ISO has begun a preliminary analysis of the benefits of large-scale pumped storage in regards to ramping and curtailment risk based on our 2014 LTPP modeling, and the results are promising. The ISO intends to further incorporate this initial work into its 2015-2016 transmission planning process. The ISO looks forward to sharing this study with the Commission and to using the results to inform potential procurement in the 2016 LTPP."

While we await the results of the CAISO's study, the statement itself is historically important new information that, coming from the public entity responsible for reliability, warrants a revisiting of the Commission's exclusion of pumped storage from procurement authorization in this proceeding. Revisiting does not mean that the Commission should immediately authorize procurement, but it does mean that it should adopt the following sequential approach:

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[11] *Notice of Ex Parte Communication by the California Independent System Operator*, filed July 22, 2015. The same letter was also filed in the 2014 LTPP docket (R.13-12-010).

1. Immediately initiate a six-month, transparent process to determine pumped storage's net benefit to ratepayers served by the Commission, and, if net benefit is deemed to be positive, then
2. Initiate a process to determine how procurement of pumped storage should work as contemplated above regarding multi-IOU procurement, which can only be required by the Commission.

C. EDF RE's Extensive PLEXOS Analysis Points to Pumped Storage's High Value for California.

EDF RE has already completed sophisticated modelling of the Swan Lake North project, described in Appendix A, to determine the net benefit for IOUs in California. The result of the modelling is a finding of strong net benefit value in light of 50% renewables penetration, and higher value compared to a proxy flexible gas-fired resource. Value is denominated in system-wide production cost savings, avoidance of renewables curtailment, and reduction of GHG emissions. The analysis assumes increased regional grid integration and full implementation of the 1.3-GW ESP target, such that pumped storage is not seen in isolation of these important system-wide flexibility tools.

The analysis examines value provided in 2022 as a representative year, and divided into two parts:

(1) Part A: value provided by Swan Lake North under a 50% RPS scenario in 2022 compared to no new pumped storage project, with 36.4% renewables serving California load that year, and

(2) Part B: value provided by Swan Lake North under a fully implemented 33% RPS scenario in 2022 compared to the same capacity of flexible, gas-fired LMS100 generation.

The results of the analysis are the following:

Table 1. PLEXOS Study Part A (50% RPS, 36.4% Renewables Penetration, Incremental Value of Swan Lake North Compared to "No Action" Case)

	Production Cost Savings for expanded CAISO ($)	Production Cost Savings for current CAISO ($)	Avoided Renewable Energy Curtailment (GWh)	Carbon Reduction (tons)
Swan Lake North added to grid (400 MW)	$52MM	$33MM	403	390,000

Table 2. PLEXOS Study Part B (33% CA RPS, 33% Renewables Penetration, Comparison Between Incremental Value of Swan Lake North and LMS100 Options Compared to "No Action" Case)

	Production Cost Savings for expanded CAISO ($)	Production Cost Savings for current CAISO ($)	Avoided Renewable Energy Curtailment (GWh)	Carbon Reduction (tons)
Swan Lake North added to grid (400 MW)	$36MM	$26MM	199	200,000
4 LMS100 Units (400 MW)	$4MM	NA	6	30,000

The above values incorporate the following attributes:

- Load leveling / Energy arbitrage
- Regulation reserve provision
- Flexibility reserve provision
- Contingency spinning reserve provision
- Contingency non-spinning reserve provision
- Replacement / Supplemental reserve provision
- Integration of variable energy resources (VER)

- Generating capacity
- Portfolio effects
- Reduced cycling of thermal units
- Reduced environmental emissions

Regarding the Part A results, the CAISO is the major beneficiary of the total production cost reduction from Swan Lake North at $33 million per year, compared to $52 million for the entire region. The 390,000 tons of carbon reduction by Swan Lake North is due to more efficient operation of existing fossil fuel power plants plus avoided curtailment of renewable energy resources.

Regarding the Part B results, the CAISO is the major beneficiary of the total production cost reduction from Swan Lake North at $26 million per year, compared to $36 million for the entire region. The striking difference in avoided curtailed energy (199 GWh per year for Swan Lake North compared to 6 GWh per year for the LMS100) is primarily due to Swan Lake North's ability to physically store the energy that is displaced on the grid by allowing renewable energy projects to run at their full potential and then return that energy to the grid when it is needed providing a GHG emission reduction of 200,000 tons. By contrast, 30,000 tons of carbon reduction was achieved when the LMS100 complex was substituted into the grid.

1. Modelling Tools, Geographic Scope and Outputs.

Energy Exemplar, LLC[12] was engaged by EDF RE to perform a PLEXOS modeling evaluation of Swan Lake North. The CAISO employs PLEXOS extensively in the daily optimization of the grid, and it is used by all of California's IOUs in their long-term planning.

[12] http://energyexemplar.com/

PLEXOS models electrical grids using a production cost approach. The production cost approach looks at the marginal dispatch cost of every generator in the observed "Focused Region" defined by EDF RE as California, Oregon, Washington and Nevada, and compares this data set to the load of the region. The model then optimizes the dispatch of all of the generators in a way to provide the full requirements of the regional load at the least cost. The outputs of the evaluation include the total production cost which has been minimized, and a variety of additional outputs about how the generators were dispatched as exemplified by examples such as the revenue created from market based products, the amount of carbon generated, and the amount of required renewable generation curtailment.

The PLEXOS model arrives at the optimized production cost dispatch of the Focused Region generators by a three step process of re-optimization that reflects real-life scheduling done by grid operators and participants. Each step represents a scheduling window, and includes: 1) day-ahead scheduling, 2) hour-ahead scheduling, and 3) real-time (5 minute) scheduling. As production costs are minimized for the Focused Region, fuel costs are minimized and energy storage is utilized in a way to store energy at the most optimal times and retrieve it to serve the grid when it is most valuable.

The final analysis represents the current state of the development project's operational characteristics. The analysis modeled Swan Lake North as a 393.3 MW facility with direct interconnection to the Malin Substation on the California-Oregon Intertie. Due to the long computational run time of the PLEXOS software, the analysis thus far only models the first full year of anticipated operations, 2022, as a reference year.

2. Modelling Scenarios.

The PLEXOS analysis covers several scenarios to understand the influence of natural gas price volatility and 33% and 50% RPS requirements for California on the values that the project could offer. The scenarios include both a 33% and then a proposed 50% RPS noting that the analysis occurred before enactment of SB 350.

The scenarios entail three runs:

- A base case that did not include Swan Lake North nor an alternative "proxy" resource, to serve as a control group of outputs
- A modified case of including Swan Lake North into the grid, with a comparison with the base case
- A modified case of including an LMS100 flexible gas-fired generation complex into the grid, with a comparison with the base case

The analysis chose the LMS100 generation complex, a series of 4 X LMS100 flexible gas turbines, as a close proxy for an alternative capacity product that could provide similar levels of ancillary services and peak generation as could Swan Lake North. One key drawback of the LMS100 that is highlighted in the output data when contrasting the LMS100 to Swan Lake North is that the flexible gas generator's inability to store energy limits its potential benefits significantly to the grid relative to energy storage.

While the comparison to new, flexible gas-fired generation is at the 33% RPS level, the results do give a direction of value improvement, and a relative degree of value provided between the two technologies. It is expected that the direction would maintain and the degree would even be more pronounced under the 50% RPS target for this type of comparison.

3. Assumptions and Inputs.

The primary assumptions and inputs used in the PLEXOS modeling are critical, and include the following to best represent the world as it is.

Assumptions include:

- Inclusion of future storage based on the fulfillment of AB2514 adding 1.3GW of new small scale energy storage (primarily battery technology)
- The Focused Region was assumed to have evolved into one balancing authority with LMP nodal pricing for the entire area as an expansion of the current CAISO into a larger Western ISO
- California RPS levels of 50% in the case of Part A, and 33% in the case of Part B. These RPS target translate into renewables penetration to serve California load in 2022 of 33% and 36.4% respectively for the 50% and 33% RPS target.
- No new transmission in the region, given the difficulty of isolating and building transmission expansion projects to meet load balancing requirements into the model.

Inputs include the following and are focused on maintaining consistency with other prominent modelling sources such as the Western Electric Coordination Council ("WECC") Transmission Expansion Policy Planning Committee ("TEPPC"), the independent consulting firm E3 in their analysis commissioned by IOUs[13], and the National Renewable Energy Laboratory ("NREL") reference studies[14]:

- The TEPPC 2022 database as the starting point for generator inputs.

[13] Final Phase 1 Report for Consideration in CPUC A. 14-02-006. Energy and Environmental Economics (E3). June 19, 2014: 22-23. Online at: https://www.caiso.com/Documents/E3StorageValuationFinalPhase1.pdf.

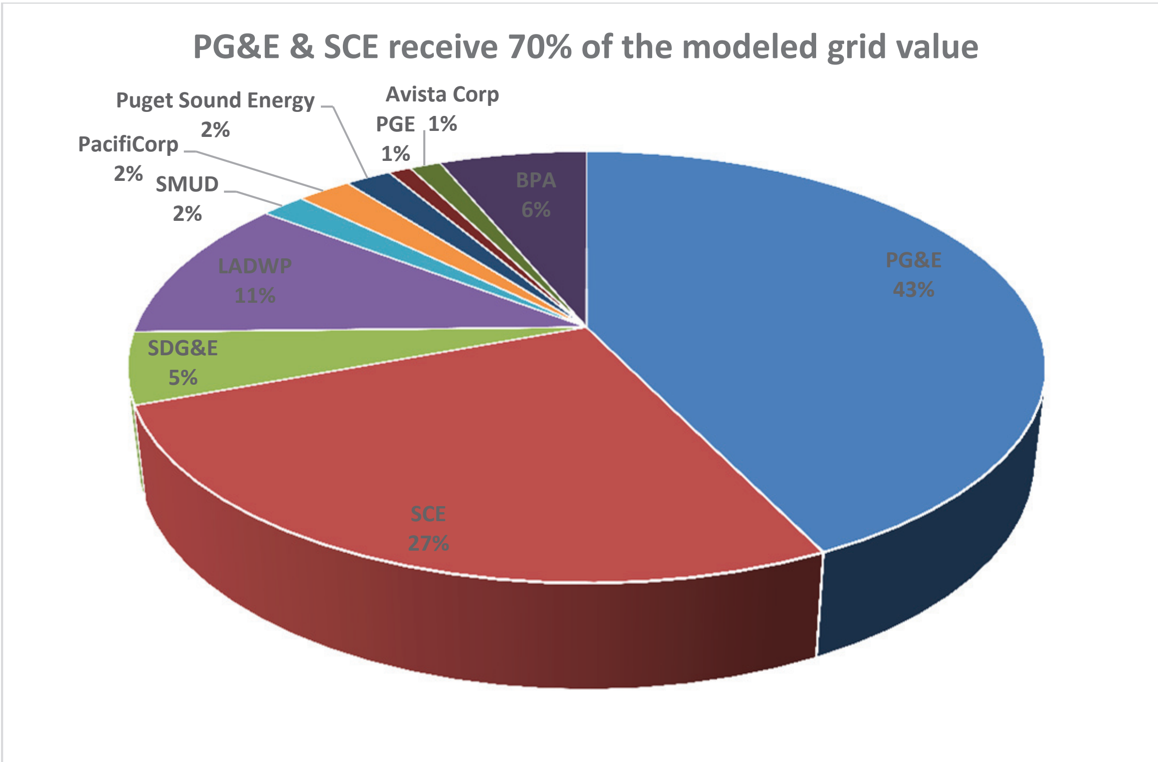
[14] *See,* footnote number 5, *infra*.

- Modification of the TEPPC 2022 database for Pacific Northwest hydro generators to better reflect typical water storage and flexible capability in light of environmental restrictions on operations for fish protection.
- NREL regional load data for 2020 and escalated to 2022.
- Wind and solar generation profiles from 2020 NREL data escalated to 2022 reflecting anticipated deployment rates tied to a linear deployment of renewable energy projects to meet the RPS targets of the states in the Focused Region.

4. Value Provided to Individual California IOUs.

The analysis also yielded specific value data for each load-serving entity in the region. For the Part A analysis (50% RPS path), we provide the benefits provided to regional utilities, including California's IOUs, that in total receive the substantial majority of benefits, in Figure 1 below. The distribution of benefits generally accrues to the IOUs and are in part a function of Swan Lake North's location.

Figure 1. Distribution of Swan Lake North Value in 2022 Among Regional Utilities Under a 50% RPS Path (36.4% Renewables Serving California)



The three California IOUs accrue 75% of the total value of Swan Lake North.

5. Interpretation.

Swan Lake North can provide a significant bundle of benefits to the region and specifically for the California IOUs. Under a 50% RPS scenario entailing 36.4% renewable penetration in 2022, there is a large direct economic benefit of the $52 million per year in production cost reduction from Swan Lake North. Simultaneously, Swam Lake North also achieves 390,000 tons of carbon reduction through a more optimal and efficient use of existing fossil fuel power plants and avoided curtailment of renewable energy resources.

The avoided curtailment of renewable energy resources is a three-fold benefit in that it: (1) allows renewable energy projects that have already been paid for by utility customers the ability to run and generate electricity; (2) eliminates the need for a back-up fossil fueled power plant to have to run in place of the curtailed renewable energy projects at an additional cost (this would raise the grid total production cost); and (3) eliminates the carbon associated with the dispatch of the makeup fossil fueled power plant.

By comparison to the next best marginal cost technology for providing flexible capacity, the LMS100, Swan Lake North is the superior technology. Under a 50% RPS scenario in 2022, Swan Lake North is economically superior as it reduces total production cost by $32 million per year more than an LMS100 complex. Furthermore, Swan Lake North is a superior complimentary technology to renewable energy because it allows considerable avoided renewable curtailment, whereas the LMS100 complex offers nearly no mitigation of renewable curtailment. This complimentary ability will allow pumped storage hydropower to be built concurrently with new renewable energy projects to provide a more balanced grid of the future. Finally, Swan Lake North is environmentally superior in that it provides a substantial decrease in carbon by as much as 170,000 tons per year more than the LMS100 complex.

We also note that the above results implicitly co-exist with the benefits provided by the full implementation of the current ESP Framework. While we do not model an increased ESP target in its current design alongside Swan Lake North in 2022, we again point to analyses such as that by UCS that describes the need for energy storage beyond the capacity offered by Swan Lake North and the current scale of the ESP target. Hence, more energy storage beyond Swan Lake can benefit California early next decade. We also note that the results exist in a scenario of increased regional grid integration, which is another “flexibility tool” elaborated by the Commission elsewhere (e.g., White Paper).

6. Further Information On EDF RE's PLEXOS Analysis

Further background and detail on the analysis discussed above can be found in Appendix B attached to these comments.

V. CONCLUSION

We find that the increased amount of analysis outside of the Commission points to the need for more energy storage, and the particular value of pumped storage as a part of a significantly larger energy storage portfolio. Enactment of SB 350 has made selection of viable, cost-effective, and carbon-minimizing options paramount and consistent with the statutory goals of AB 2514. The longer lead time of viable pumped storage project development, and the clear need for more flexible tools to serve California ratepayers early next decade requires the Commission to initiate a six-month analysis of new pumped storage project value within a carbon-constrained, 50% renewables future for the state.

The results of the analyses, if they indicate pumped storage's net positive value for ratepayers, should then compel the Commission to initiate a process among its regulated IOUs to determine how competitive joint procurement for a new pumped storage project should work. Such procurement need not and should not occur within the current ESP Framework, but rather entail a separate procurement process. Such procurement can draw upon some of the contractual aspects of the existing ESP Framework, with strong controls for viability, financial commitment by the supplier and sound cost allocation among the benefitting IOUs.

To date the Commission's implementation of AB 2514 has focused on market transformation. The focus beyond the current ESP Framework should be on need, and in that case pumped storage's strong positive value to California ratepayers should require an end to its exclusion from AB 2514 implementation. We appreciate the opportunity to comment and also appreciate the Commission's ongoing hard work in this proceeding.

Respectfully submitted,

Virinder Singh
Director - Regulatory & Legislative Affairs
EDF RENEWABLE ENERGY, INC.

Date: February 5, 2016

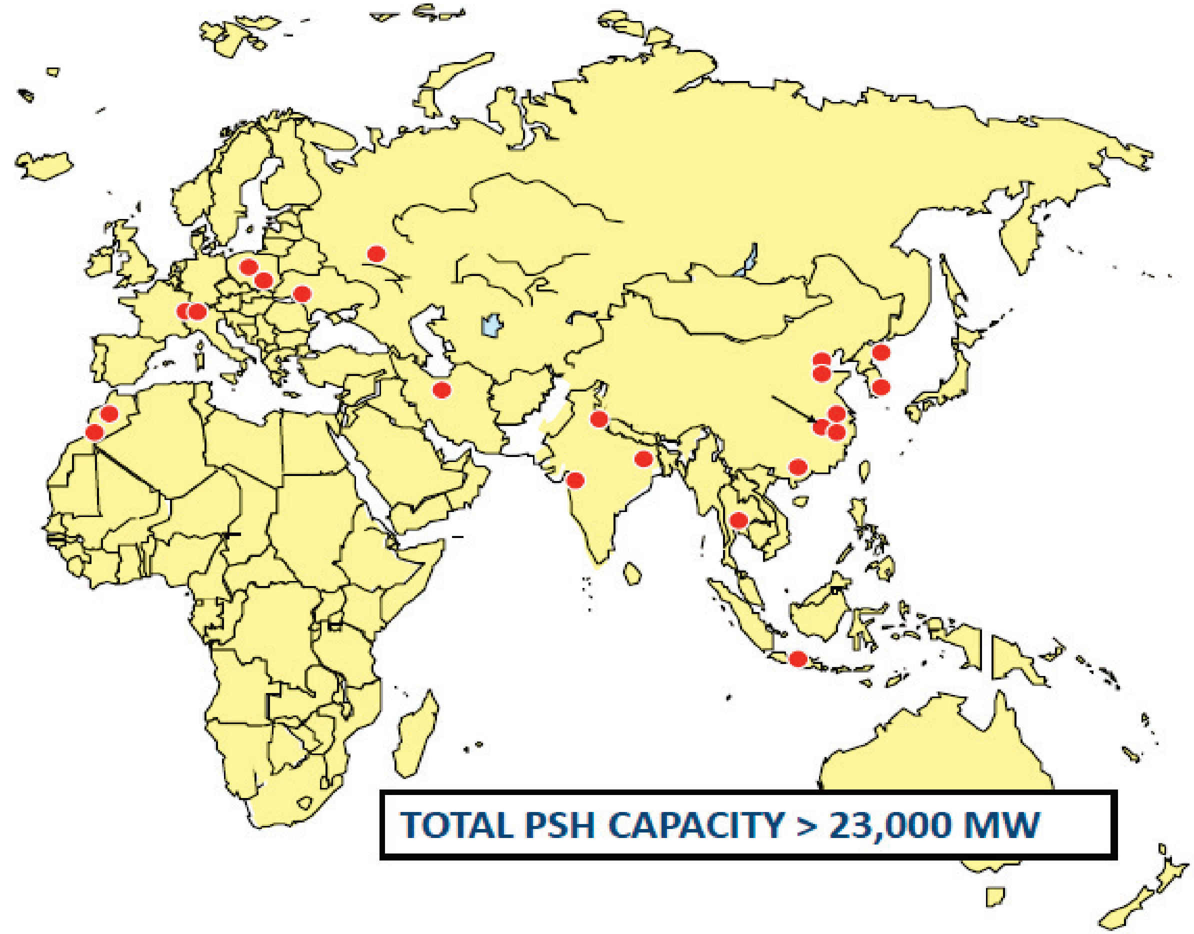
APPENDIX A

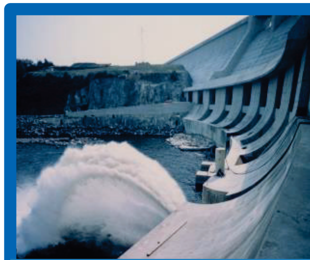
PUMPED STORAGE HYDROPOWER (PSH)
02/03/16

Swan Lake North

EDF PUMPED STORAGE HYDROPOWER (PSH) EXPERIENCE

Global Overview of EDF Pumped Storage Hydropower Projects





EDF brings Unparalleled Global Experience

- 600 hydroelectric schemes
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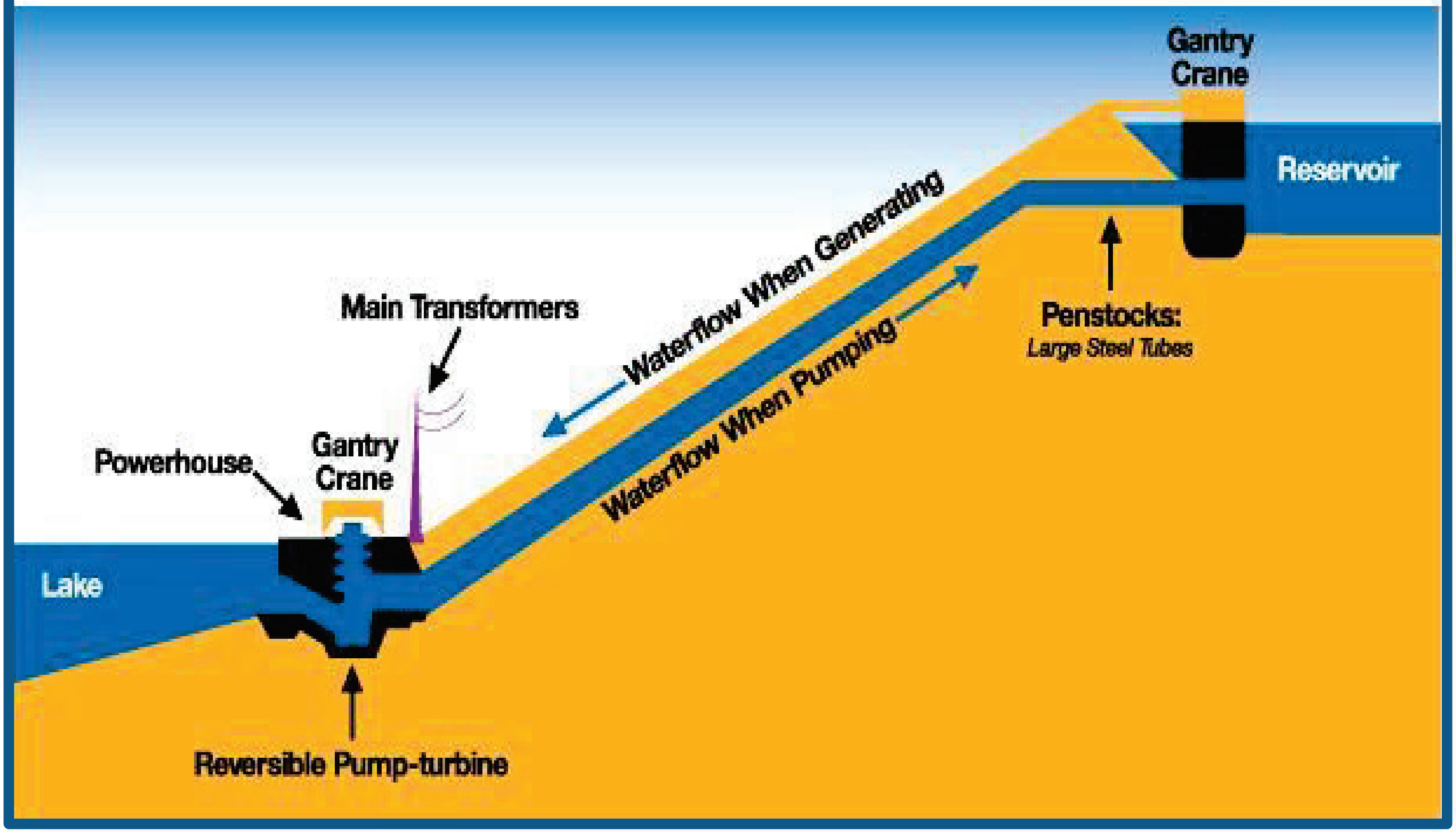
PROJECT DESIGN

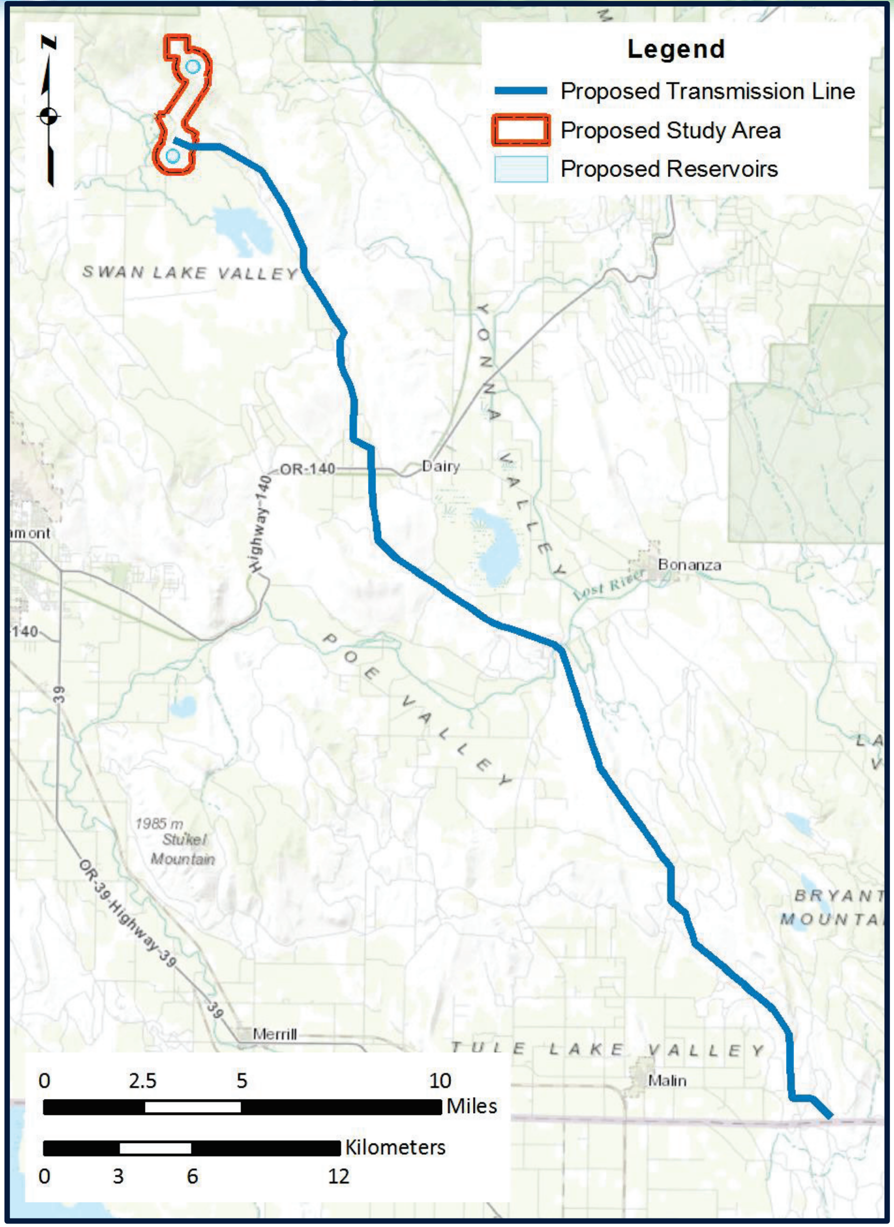
Current Swan Lake North Design



SWAN LAKE NORTH
pumped storage hydro

PROJECT CHARACTERISTICS

LOCATION	Approx 11 miles NE of Klamath Falls
CAPACITY	393.3 megawatts (MW) Generation Mode 415.8 MW Pumping Mode
PROJECT HEAD	1,680 feet
PROPERTY	Private & BLM
WATER AVAILABILITY	Leased groundwater rights, preliminary OWRD approval
TRANSMISSION ACCESS	At Malin Substation; near COB market; PacifiCorp or BPA with access to CAISO
CLOSED-LOOP SYSTEM	New upper and lower reservoirs No impact to existing water ways Initial fill and evaporation makeup from existing ground water wells
FACILITY DESIGN	Above ground powerhouse and penstock



APPENDIX B

Leading the field in
Power Market Modelling

Swan Lake Pumped-Storage Facility Economic Evaluation using PLEXOS

PHASE 3

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List of Acronyms

ANL – Argonne National Laboratory
AS PSH – Adjustable Speed Pumped-storage Hydro Generator
AS – Ancillary Services
BA – Balancing Area
BAA – Balancing Authority Area
BPA – Bonneville Power Administration
CAISO – California Independent System Operator
COI – California-Oregon Interface
DA – Day-Ahead
DOE – US Department of Energy
EDF-RE - EDF Renewable Energy
FS PSH – Fixed Speed Pumped-storage Hydro Generator
GWh – Gigawatt-hours
HA – Hour-Ahead
LTPP – Long Term Procurement Plan
NREL – National Renewable Energy Laboratory
PACW – Pacific Corps West
PNNL – Pacific Northwest National Laboratory
PSH – Pumped-storage Hydro
RPS – Renewable Portfolio Standards
RT – Real Time
SCED – Security Constrained Economic Dispatch
SCUC – Security Constrained Unit Commitment
TEPPC – Transmission Expansion Planning and Policy Committee
WI – Western Interconnection
WECC – Western Electricity Coordinating Council
WWSIS – Western Wind and Solar Integration Study

Executive Summary

Energy Exemplar was engaged by EDF Renewable Energy (EDF-RE) for the economic evaluation of the Swan Lake Pumped-storage Hydro (PSH) project's benefits to the grid in different market conditions, using the PLEXOS, an integrated power market simulation software suite.

The report is developed for the Phase 3 study. In this phase study, Swan Lake PSH is proposed to be a 393.3 MW generating mode (and 415.8 MW pump mode) Pumped-storage Hydropower facility located about 11 miles northeast of the Klamath Falls, Oregon. This project has transmission access to the Malin substation near California-Oregon Border on the COI and the Malin-Round Mtn #2 line to PG&E. Therefore, it can connect to the PacificCorp's grid on the north via Malin as well as the CAISO's grid to the south via PacifiCorp.

Assumptions

To capture the benefits of Swan Lake PSH in detail, a West Interconnection (WI) database, with the nodal transmission network representation, was prepared and configured to be as close to the reality as possible. The WI database is originated from the WECC TEPCC 2022 database with assumption updates for this study. In this modeled evaluation, the focus study region is reduced to the Balance Authority Areas (BAAs) in the states of Washington, Oregon, California and Nevada near the PSH facility.

In 2013, Energy Exemplar worked with the Argonne National Laboratory (ANL) for a DOE sponsored project to evaluate the Fixed-speed Pumped-storage Hydro generators (FS PSH) and the Adjustable-speed Pumped-storage Hydro generators (AS PSH). In that ANL study, many new assumptions, such as load forecasts, renewable generator capacity, location and profiles, etc., were received from two National Laboratories and incorporated into the WI database. Some other assumptions in that study were further updated according to the feedbacks from a large stakeholder group that consists of more than 30 industry experts. There are many similarities between the Swan Lake PSH evaluation in this study and the ANL study, in terms of the assumptions and the modeling approach. Therefore, this study uses the ANL study as a template and some assumptions were inherited from the ANL study, such as:

- Load forecast, including the Day-Ahead, Hour-Ahead, and Real Time loads
- Renewable generation profiles, including wind and solar data in DA, HA and RT
- Existing generators' characteristics
- Ancillary Service grouping and the generator contributors for each group
- Existing pumped-storage generators and their characteristics
- Fuel price forecasts other than the natural gas forecast
- Penalty prices for all constraints
- Others

Other assumptions were updated in this study, including:

- Swan Lake PSH's characteristics
- Renewable penetration level for all states in the WI
- Wind and solar mix ratio for all states in the WI
- Renewable curtailment price
- Operational constraints for several hydro generators in the northwest
- Natural gas price forecast
- Ancillary Services bidding prices for different types of generators
- The characteristics of LMS100 CT, which is the alternative equivalent for Swan Lake PSH

Modeling Approach and Scope

This study evaluates Swan Lake PSH by using the PLEXOS's three-stage DA/HA/5-min RT sequential simulations, which imitates the real world ISO market and BAA operation. The simulated and analyzed cases are listed in the following table.

Group	Scenario[1]	Evaluated Resources	RPS % in California	Gas Price
1: Base RPS and Base Gas Price	A base	N/A	33%	Base
	A	Swan Lake 393.3 MW	33%	Base
	D-2	LMS100 400 MW	33%	Base
2: Base RPS and High Gas Price	E-1 base	N/A	33%	High
	E-1	Swan Lake 393.3 MW	33%	High
	E-2	LMS100 400 MW	33%	High
3: High RPS and Base Gas Price	C base	N/A	50%	Base
	C	Swan Lake 393.3 MW	50%	Base

For each group, the WI is simulated at the nodal transmission network representation for year 2022. For each scenario, the 3-stage DA/HA/5-min RT sequential simulation is performed at the nodal transmission network representation for the focused regions of CA, NV, OR and WA for year 2022. In the 3-stage DA/HA/5-min RT sequential simulations, the intertie flows between the focused regions and the rest of WI from the WI simulations are frozen.

Results and Findings

The solutions and analyses presented in this report include

1. Swan Lake PSH's impact to the production cost for the focused regions and the major BAs in the focused regions,
2. Swan Lake PSH operation and net revenue and the comparison with LMS100,

[1] The Scenario IDs are used to match the simulation scenario IDs in the Scope of Work for Phase 3.

3. Swan Lake PSH's impact to the generation and generation cost by generator type,
4. Swan Lake PSH's impact to the renewable curtailment in the major BAs in the focused regions,
5. Swan Lake PSH's impact to the emission production in the major BAs in the focused regions, and
6. Swan Lake PSH's impact to the thermal generator cycling in the major BAs in the focused regions.

All the results mentioned here are based on the annual total for the modeled study year 2022. The cost and revenue values are based on the 2022 real US dollar.

The findings from the simulation result analyses are listed as follows.

Production Cost Savings in Focused Regions

With Swan Lake PSH, the focused region production cost reductions from the RT simulations are listed in the following table.

Comparison of the Production Cost Reduction in the Focused Regions and CAISO from the 5-min RT Simulations (million $)			
Case	Base RPS and Base Gas Price	Base RPS and High Gas Price	High RPS and Base Gas Price
Focused Regions	$36	$37	$52
CAISO	$26	$28	$33

It is obvious that CAISO benefits most from Swan Lake PSH.

The production cost reduction from 400MW of LMS100 are only in the range of 4 to 11 million $ in the focused regions by comparison.

The 3-stage sequential simulation solutions show that the production costs from the 5-min RT simulation are much higher than that from the DA simulation due to the generator cycling to cover the 5-min load and renewable uncertainty and variability in the 5-min RT operation. The following table shows the production cost comparison between the DA simulations and the 5-min simulations. The production cost from the 5-min RT simulations is about 5~7% higher than that from the DA simulations.

Comparison of the Production Cost from the DA Simulations and the 5-min RT Simulations						
	Base RPS and Base Gas Price		Base RPS and Base Gas Price		Base RPS and Base Gas Price	
	Base	Swan Lake	Base	Swan Lake	Base	Swan Lake
DA Production Cost (mill$)	6,294	6,276	6,791	6,777	5,909	5,883
RT Production Cost (mill$)	6,604	6,568	7,124	7,087	6,317	6,263
Difference (RT - DA) (mill$)	310	292	333	310	408	380
% of Diff (RT - DA)/DA	5%	5%	5%	5%	7%	6%

Swan Lake PSH Operation Performance

If Swan Lake PSH is operated as an independent power producer, it will receive the energy and AS revenue at the LMP and AS price, and will pay the pumping energy cost at the LMP. The net revenue is the energy and AS revenue less the pumping cost. The following table shows the Swan Lake PSH capacity factor and net revenue from the 5-min RT simulations.

Comparison of Swan Lake PSH Capacity Factor, Net Revenue, and Capacity Value from the 5-min RT Simulations			
Case	**Base RPS and Base Gas Price**	**Base RPS and High Gas Price**	**High RPS and Base Gas Price**
Capacity Factor (%)	33	32	35
Net Revenue (mill$)	39	41	53
Capacity Value ($/kW-Year)	100	105	136

As a comparison, the capacity values of 400 MW of LMS100 falls in the range of 67 to 69 $/kW-year.

Impact to Other Generators

With Swan Lake PSH, the generator operations are impacted in the focused regions. The most impacted generator types are CC, CT, Hydro and Renewable. The following table summarizes the generation and generation cost changes (negative value = reduction, positive value = increase)

Comparison of Generation Changes and Generation Cost Changes from the 5-min RT Simulations						
	Base RPS and Base Gas Price		**Base RPS and High Gas Price**		**High RPS and Base Gas Price**	
Changes	**Generation (GWh)**	**Generation Cost (Mill$)**	**Generation (GWh)**	**Generation Cost (Mill$)**	**Generation (GWh)**	**Generation Cost (Mill$)**
CC	-241	-14	-332	-21	-337	-18
CT	-326	-23	-227	-19	-427	-35
Hydro	509		471		622	
Renewable	245		226		446	

It is noticeable that Swan Lake PSH displaces the thermal generators and allows more generation from hydro and renewable mostly for the pumping energy.

Contributions to Emission Reductions

Swan Lake PSH also has impact to the emission production in the focused regions. The emission production reduction in the focused regions due to Swan Lake PSH falls in the range of 170,000 to 390,000 tons.

Contribution to Renewable Generation Integration

With Swan Lake PSH, the renewable curtailments are reduced. The following table shows the summary of renewable energy curtailment reduction from the RT simulations.

Comparison of Renewable Energy Curtailment Reduction from the 5-min RT Simulations				
		Base RPS and Base Gas Price	**Base RPS and High Gas Price**	**High RPS and Base Gas Price**
Focused Regions	Renewable Energy Curtailment Reduction (GWh)	199	204	403
	% of Reduction as Curtailed Renewable Energy	6.4	6.6	1.6
CAISO	Renewable Energy Curtailment Reduction (GWh)	97	96	246
	% of Reduction as Curtailed Renewable Energy	4.7	4.7	1.2

The declining percentage of reduction in the third column is a function of a much larger amount of total renewables on the grid in the High RPS case. Note however, that the nominal amount of GWh of avoided curtailment rises significantly. The 400 MW of LMS100 has little impact to the renewable energy curtailment reduction.

Contribution to Thermal Generation Cycling Reductions

Due to the flexibility of Swan Lake PSH, the thermal generator cycling can be reduced. The thermal generator cycling includes number of starts, start cost, ramp up and down mileages.

The following table shows the thermal generator number of starts and start cost reduction by Swan Lake PSH from the 5-min RT simulations.

Comparison of Thermal Generator Number of Starts and Start Cost Reduction from the 5-min RT Simulations				
		Base RPS and Base Gas Price	**Base RPS and High Gas Price**	**High RPS and Base Gas Price**
Focused Regions	Number of Start Reduction	2,469	1,806	3,111
	% of Number of Start Reduction	4.8	3.6	5.1
	Start Cost Reduction (mill$/year)	10.66	11.04	14.09
	% of Start Cost Reduction	3.0	3.0	3.6

CAISO	Number of Start Reduction	1,711	1,297	1,867
	% of Number of Start Reduction	4.5	3.4	4.3
	Start Cost Reduction (mill$/year)	7.37	8.53	8.01
	% of Start Cost Reduction	3.6	4.0	3.6

The following table summarizes the thermal generator ramp up and down mileages.

Comparison of Thermal Generator Ramp Up and Down Mileages Reduction from the 5-min RT Simulations				
		Base RPS and Base Gas Price	**Base RPS and High Gas Price**	**High RPS and Base Gas Price**
Focused Regions	Ramp Up Mileages Reduction (GW/year)	396	370	353
	% of Ramp Up Mileages Reduction	3.4	3.3	3.0
	Ramp Down Mileages Reduction (GW/year)	437	417	391
	% of Ramp Down Mileages Reduction	3.3	3.2	2.9
CAISO	Ramp Up Mileages Reduction (GW/year)	235	200	198
	% of Ramp Up Mileages Reduction	3.3	2.8	2.8
	Ramp Down Mileages Reduction (GW/year)	263	238	200
	% of Ramp Down Mileages Reduction	3.2	2.9	2.4

As a comparison, the 400 MW of LMS100 has little impact to the thermal generator cycling.

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1 Introduction

Energy Exemplar was engaged by EDF Renewable Energy (EDF-RE) for the economic evaluation of the Swan Lake Pumped-storage Hydro (PSH) project's benefits to the grid in different market conditions, using the PLEXOS, an integrated power market simulation software suite[2].

This report presents the Phase 3 (SOW#3) assumptions, simulation solutions and analysis. For the detailed description of Phases 1 and 2 assumptions, simulation solutions and analysis, please refer to project report "*Swan Lake Pumped-Storage Facility Economic Evaluation using PLEXOS*" by Energy Exemplar, December 2014.

In Phase 3, the following assumptions are included in the database used for the Phases 1 and 2 study.

1. Swan Lake PSH is assumed 393.3 MW of generating capacity and actual 415.8 MW of pumping capacity, and
2. California 1.325 GW energy storages with the storage sizes of 2 hours, 4 hours and 6 hours.

The solutions of following assumptions are analyzed respectively.

1. 33% Renewable Portfolio Standard (RPS) in California;
2. 50% renewable portfolio standard (RPS) in California;
3. Regular gas price and high gas price forecasts

For the comparison, four 100MW LMS100 Gas Turbine generators are simulated as well.

The same assumptions as in Phases 1 and 2 are re-iterated as follows.

As shown in the following diagram, Swan Lake PSH is proposed to be located about 11 miles northeast of the Klamath Falls, Oregon. This project has transmission access to the Malin substation near California-Oregon Border on the COI and the Malin-Round Mtn #2 line to PG&E. Therefore, it can connect to the PacificCorp's grid on the north via Malin as well as the CAISO's grid to the south via PacifiCorp.

[2] For more information about PLEXOS, visit www.energyexemplar.com

Figure 1-1 Swan Lake Project Site

In order to capture the benefit of Swan Lake PSH in detail, a database was prepared and configured to be as close to the reality as possible. The footprint of the database is originated from a WECC database which includes the entire Western Interconnection (WI) power grid at bus level. In this modeled evaluation, the focus study region is reduced to the Balance Authority Areas (BAAs) in the states of Washington, Oregon, California and Nevada near the PSH facility.

The database simulates the Focused Regions to imitate the current CAISO system operation, with the three-stage simulation among Day-Ahead (DA) Market, Hour-Ahead (HA) Market, and the 5-simute Real Time (RT) market. PLEXOS can simulate the co-optimization structure between the energy market and various ancillary service markets as in the CAISO operation. It is important to capture the true value of the pumped-storage facilities and their flexibility in such environment.

In this study, Energy Exemplar performed a base case study as well as the alternative cases to better understand the Swan Lake PSH's values. For the base case and the alternative cases, we examine the Swan Lake PSH's impacts to the BAAs in the focus study region by comparing several indices between the system without the Swan Lake project and the system with the Swan Lake project.

In 2013, Energy Exemplar was engaged in a similar Pumped-storage evaluation project sponsored by the Department of Energy through Argonne National Laboratory (ANL) to perform the power system operation simulation to evaluate the Fixed-speed Pumped-storage Hydro-generators (FS PSH) and the Adjustable-speed Pumped-storage Hydro-generators (AS PSH) in the areas of

1. Quantifying the value of the FS and AS PSHs under different market conditions and for different levels of variable renewable generation (wind and solar) in the system;
2. Providing information about the full range of benefits and value of PSH and CH plants and recommendations for appropriate business models for future PSH projects.

In that study, a whole set of input assumptions were formed and then verified by a large group of stakeholders. Some of the assumptions from that study were inherited in this Swan Lake evaluation. The other assumptions were updated according to the new data available as well as the market evolutions or the possible evolutions since then.

For the rest of the report, Section 2 describes Database Preparation and Assumption Revisions; Section 3 describes

Modeling Approaches; Section 4 presents Simulation Result; Section 5 summarizes Findings.

2 Database Preparation and Assumption Revisions

2.1 Database Preparation

The database prepared for this study was originally from the WECC TEPPC 2022 Common database [1, 2]. It has been converted to a PLEXOS database and further updated during Energy Exemplar's previous Argonne National Laboratory Pumped-storage evaluation study (referred as "ANL PSH Study" hereafter) [3]. The TEPPC 2022 database covers the entire footprint of the Western Interconnection (WI). As shown in Figure 2-1, there are total of 39 load regions in WI footprint, representing the Balance Authorities (BAs) and/or its sub-regions in the United States, plus the provinces of British Columbia and Alberta in Canada, and Comision Federal de Electricidad (CFE) in northern Mexico.

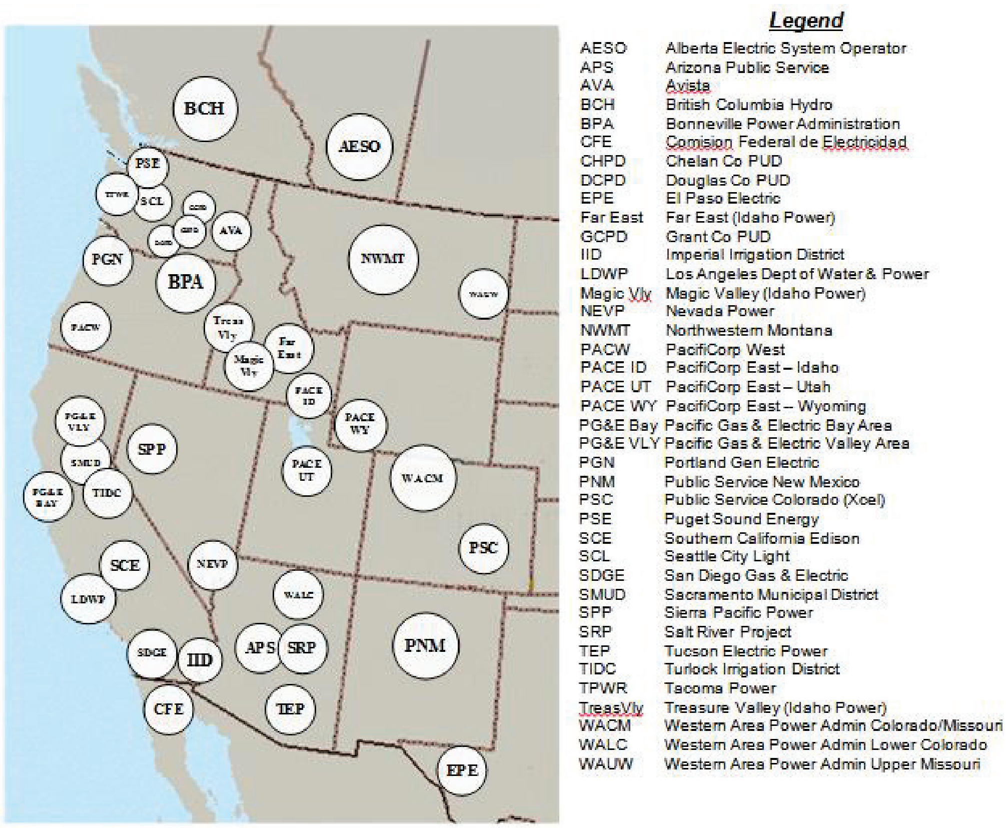

Figure 2-1 Diagram of the WECC Load Regions (Source: WECC)

The entire WI network consists of over 17,000 buses, over 22,000 transmission lines and over 3,700 generators (including the renewables).

The regions that are far away from the Swan Lake PSH proposed site are expected to be marginally impacted by Swan Lake PSH. Therefore, the following focus study region is electrically "carved out" from the original WI footprint from the modeling perspective, as shown in Figure 2-2. The selected focus study region includes the Balance Authorities

(BAs) and/or its sub-regions in the four states: Washington, Oregon, California and Nevada. The intertie flows are maintained between the Focused Regions and the rest of the WI system. The detailed approach is described in Section 0.

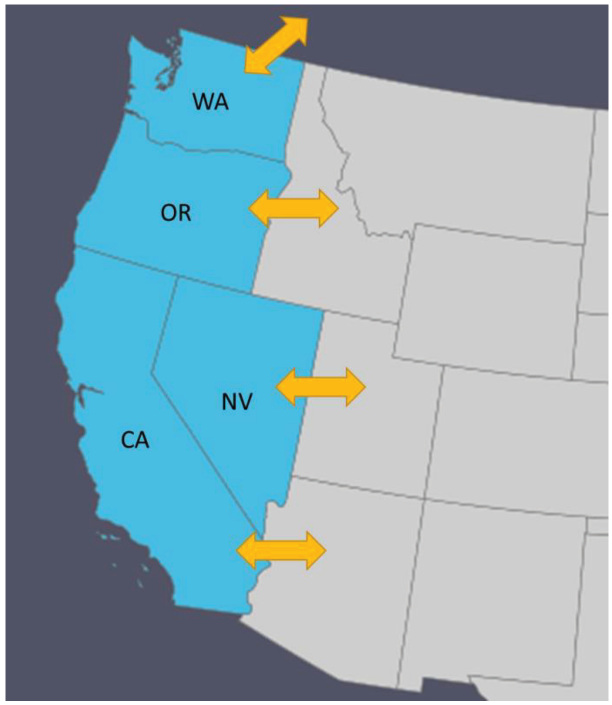

Figure 2-2 The Carved-out Focused Regions for This Study

2.2 Assumptions Inherited from the ANL Pumped-storage Study

The original assumptions in the ANL PSH study are further revisited and verified several times between EDF-RE, Energy Exemplar and other industry experts. Some assumptions are determined to be maintained as in the ANLS PSH study. This section provides some highlights for the major assumptions inherited from that study. The detailed information can be found in the ANL PSH Study report [3].

2.2.1 Regional load

The Day-Ahead (DA) and Hour-Ahead (HA) load forecasts and 5-min Real Time (RT) "actual loads" in year 2020 were received from Pacific Northwest National Laboratory (PNNL) for the WECC VGS study [5]. The three sets of loads will be used to mimic the load deviation from DA to RT in a typical ISO environment. The hourly and 5-min loads in year 2020 are translated to year 2022 with the weekly patterns synchronized in these two years. Then the DA and HA load forecasts and the RT 5-minutes loads in year 2022 are scaled by the peak ratios between year 2022 and year 2020 defined in 2022 TEPPC database [1, 2]. The peak ratios are calculated using the load regional peaks in the

WECC TEPPC 2020 and 2022 database documents [1, 2]. A summary of the total annual energy demand for the Focused Regions are listed below in Table 2-1[3].

State	Load Area	Day-Ahead	Hour-Ahead	Real Time
CA	SCE	114,442	114,758	115,041
	PG&E_BAY	48,852	48,997	49,128
	PG&E_VLY	66,111	66,293	66,453
	SMUD	18,670	18,608	18,502
	TIDC	3,174	3,157	3,139
	IID	4,696	4,697	4,700
	LDWP	30,681	31,586	32,499
	SDGE	24,542	24,612	24,674
CA Total		**311,168**	**312,708**	**314,137**
NV	NEVP	27,883	28,066	28,240
	SPP	12,802	12,766	12,730
NV Total		**40,685**	**40,832**	**40,970**
OR	PACW	19,335	20,003	20,677
	PGN	23,569	23,529	23,490
OR Total		**42,904**	**43,532**	**44,168**
WA	AVA	15,085	15,058	15,033
	BPA	60,304	58,970	57,640
	CHPD	4,060	4,062	4,066
	DOPD	2,212	2,175	2,139
	GCPD	4,964	5,071	5,178
	PSE	26,471	26,450	26,404
	SCL	11,012	10,955	10,897
	TPWR	5,557	5,490	5,420
WA Total		**129,664**	**128,230**	**126,777**

Table 2-1 Total Annual Energy Demand for DA, HA and RT simulation (GWh)

2.2.2 Renewable Generation Profiles

The wind and solar hourly day-ahead (DA) and 4-hour-ahead (4-HA) generation forecasts and the real-time (RT) 5-min “actual” generation forecasts in year 2020 were from the NREL WWSIS phase 2 study [6]. The three sets of profiles will mimic the renewable generation variability from the DA to RT markets. The hourly wind and solar generation forecasts for the DA and HA markets and the 5-min RT “actual” generation profiles in year 2020 are translated into year 2022 with the weekly patterns synchronized in these two years.

[3] Please refer to Figure 2-1 for the load area acronyms

2.2.3 Contingency, Flexibility and Regulation Reserves

2.2.3.1 Contingency Reserves

The requirements of the contingency reserves, i.e. spinning and non-spinning reserves are defined for 5 spinning reserve sharing groups. The mapping between the 5 spinning reserve sharing groups and the 20 load regions is specified in Table 2-2.

Spin/Non-Spin Reserve Sharing Group	Load Region
NEVP	NEVP
SPP	SPP
CALIF_NORTH	PG&E_BAY
	PG&E_VLY
	SMUD
	TIDC
CALIF_SOUTH	IID
	LDWP
	SCE
	SDGE
NWPP	AVA
	BPA
	CHPD
	DOPD
	GCPD
	PACW
	PGN
	PSE
	SCL
	TPWR

Table 2-2 Mapping of the load regions and the contingency reserve sharing groups

The spinning reserve requirement in a contingency reserve sharing group is 3% of the load in the group. The spinning reserve is provided by the eligible on-line generators in the group. The non-spinning reserve requirement in a contingency reserve sharing group is 3% of the load in the group as well. The non-spinning reserve is provided by the eligible on-line generators and the off-line quick startup generators in the group [3].

2.2.3.2 Flexibility and Regulation Reserves

The hourly flexibility and regulation reserve requirements for the DA, 4-HA simulations and the 5-min regulation reserve requirements for the 5-min RT simulations in year

2020 are received for the base and high-wind renewable scenarios from the NREL WWSIS phase 2 study [6]. The reserve requirements in year 2020 are translated to year 2022 with the weekly patterns synchronized in these two years.

The flexibility and regulation reserve requirements are defined for 10 flexibility/ regulation reserve sharing groups. The mapping between the 10 flexibility/regulation reserve sharing groups and the 20 load regions are specified in Table 2-3.

Flex/regulation Reserve Sharing Group	Load Region
California, North	PG&E_VLY
	TIDC
California, South	SCE
IID	IID
LDWP	LDWP
Nevada, North	SPP
Nevada, South	NEVP
Northwest	AVA
	BPA
	CHPD
	DOPD
	GCPD
	PACW
	PGN
	PSE
	SCL
	TPWR
San Diego	SDGE
San Francisco	PG&E_BAY
SMUD	SMUD

Table 2-3 Mapping of the load regions and the regulation / flexibility reserve sharing groups

2.2.4 Existing Pumped-storage Hydro Facilities

The location and installed capacity of the existing pumped-storage facilities included in this study are summarized in Table 2-4.

Name	Location Region	Spinning Reserve Sharing Group	Regulation Reserve Sharing Group	Number of Units	Total Capacity (MW)	Generator Type
Castaic	LDWP	CALIF_SOUTH	LDWP	6	1,175	Fixed Speed
Eastwood	SCE	CALIF_SOUTH	SCE	1	199	Fixed Speed
Helms	PG&E_VLY	CALIF_NORTH	PG&E Valley	3	1,212	Fixed Speed

Lake Hodge	SDGE	CALIF_SOUTH	SDGE	2	40	Fixed Speed
Grand Total				**12**	**2,626**	

Table 2-4 Locations and Installed Capacity of the Existing Pumped-storage Facilities

2.2.5 Other Inherited Assumptions

Other assumptions including the generator minimum capacity for different generator types, the system penalty prices to prioritize the violation order, the types of the generators that can provide certain types of reserves, the multiple points heat rate creation, etc., can be found in ANL PSH study report [3].

2.3 Assumptions updated in this Study

Some assumptions from the ANL PSH study are updated due to the market trend changes and new data sources available to this study. The highlights of the data updates are listed in this subsection and the detailed discussion is listed in Appendix A.

2.3.1 Swan Lake PSH Representation

Table 2-5 lists the Swan Lake Pumped-Storage Hydro characteristics received from EDF-RE for the Phase 3 study. Swan Lake PSH is represented by 3 units and each unit has generating capacity of 130.6 MW and pumping capacity of 139.8 MW that yields the total generating capacity of 391.8 MW and the total pumping capacity of 419.4MW. Swan Lake PSH uses adjustable speed technology so that it can provide reserves in the pumping mode as well as in the generating mode. Swan Lake PSH is capable of providing all types of Ancillary Services modeled in this study.

The storage size is 3.918 GWh that allows three units operate in generating mode for consecutive 10 hours. The cycling efficient is 76.55%.

Properties	SWAN LAKE North
Units	3
Max Cap per Unit (MW)	130.6
Min Cap per Unit (MW)	60
Max Pump Load (MW)	139.8
Min Pump Load (MW)	112.4
Upper Storage (GWh)	3.918
Lower Storage (GWh)	3.918
Cycle Efficiency	76.55%

Table 2-5 Characteristics of Swan Lake Pumped-storage Facility

Due to the specified transmission limit, a maximum 400MW capacity from Swan Lake PSH can be delivered to the California. This constraint is configured using PLEXOS' generic constraint modeling.

2.3.2 *Renewable Penetration/Mix Ratio/Curtailment Price*

Several States in the Western Interconnection have issued their Renewable Portfolio Standards, as shown in Figure 2-3, which is from the Database of State Incentives for Renewables and Efficiency (DSIRE). In order to assume a reasonable renewable penetration level for each state in the WI, the following steps are followed:

- In the database, make sure each state meets its RPS target by the year specified in Figure 2-3. If the specified year is further than the study year 2022, the linear growth is assumed to meet the RPS in the study year 2022. For example, as is shown Oregon needs meet 25% RPS targets by 2025, we assume it will fulfill 22% by 2022.
- For each state, research on the current state RPS implementation level and make sure the assumed RPS penetration in the database is not lower than the current RPS level.
- Since the renewable expansion is largely from the solar and wind generators, it is important to assume a relative mix ratio between the wind and the solar. Based on the regional potential to build the wind or solar plants, we assume the northern states in the WI will have a high wind penetration and the southern states in the WI will have a high solar penetration. The raw data for the wind the solar generators are received from the high-wind renewable generation scenario and high-solar generation scenario from the NREL WWSIS phase 2 study [6]. The total renewable generation for each state is then scaled up or down to the target renewable penetration level defined in this study.

The final State level RPS penetration is shown in Table 2-6. The wind and solar mix ratio for each state is shown in Table 2-7. The renewable curtailment price was updated by EDF-RE. That is $28/MWh for the wind plants built between 1/1/2012 and 12/31/2015, and $0/MWh for all other projects.

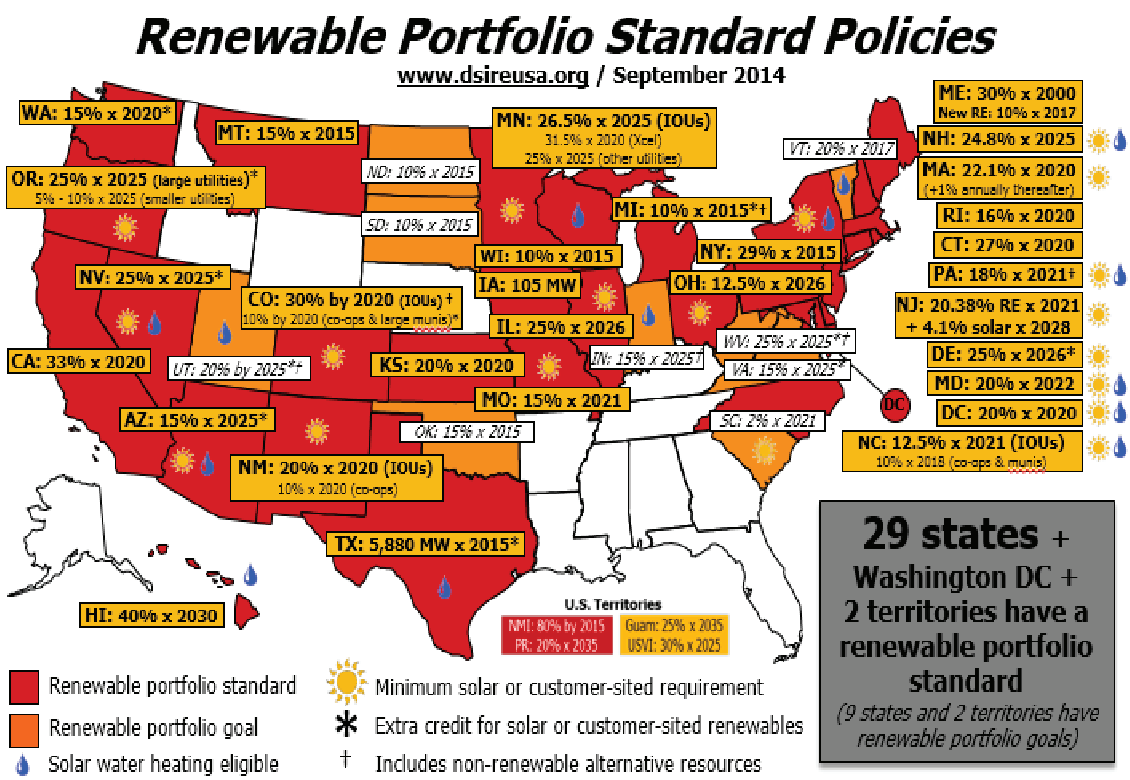

Figure 2-3 The State RPS Policies Overview (Source: DSIRE)

State	Renewable Penetration
AZ	15%
CA	33%
CO	30%
ID	16%
MT	20%
NM	20%
NV	22%
OR	22%
UT	20%
WA	23%
WY	20%

Table 2-6 Renewable Penetration Percentage for Each State of WI

State	Solar	Wind
AZ	99%	1%
CA	72%	28%
CO	8%	92%
ID	0%	100%
MT	0%	100%
NM	83%	17%

NV	97%	3%
OR	2%	98%
UT	20%	80%
WA	6%	94%
WY	1%	99%

Table 2-7 Wind and Solar Mix Ratio for Each State

2.3.3 Hydro Modeling

Traditionally, the Hydro generators are modeled either as the fixed generation profile generators to imitate the run-of-river operation, or as the dispatchable generators with limited energy within a time period. The run-of-river hydro generators are modeled with hourly running profiles that are estimated from the historical generations.

For the dispatchable hydro generators, a typical modeling method is first to dispatch the generator up to minimum generation level to imitate the run-of-river portion of the hydro generation. Then the rest of available energy for that month is dispatched at the peaking hours to reduce the system cost. The drawback of this method is that more flexibility is assumed for the dispatchable hydro plants than what they actually have. In the reality, those plants are also constrained by the water supply obligation, fish passage, recreational requirement, water flow and reservoir elevation restriction, etc., from day to day, month to month, or season to season. Though these hydro generators are able to ramp up and down quickly, their flexibility are limited by the above constraints.

In order to create the realistic hydro generation profiles for these hydro generators, a new set of updated hydro data along with more operational constraints was received from the EnergyGPS LLC, who tracks the historical operation of 60 hydro projects in the Northwest Region, and derives the operational constraints from regression analyses and observed operational patterns.

The new data package updated the hourly profiles for 21 run-of-river hydro plants. For another 21 of the largest dispatchable hydro plants, the following six constraints are defined for each of the plants:

- Maximum operating capacity by month (MW)
- Minimum operating capacity by month (MW)
- Maximum available energy by month (GWh)
- Maximum energy generation by day (GWh)
- Minimum energy generation by day (GWh)
- Daily operation range (max generation minus min generation) by day (MW)

Also the ramp rate by time of day are modeled in this study, as shown in Table 2-8, based on the regression analysis on the historical data. This is based on our observation that most of the hydro plants usually ramp up quickly during a short period in the morning, then maintain a relatively flat operation level until ramp down quickly in the last few hours of the day to a lower operating level. In this table, the "Daily Range" is one of the constraints we received from the EnergyGPS as mentioned above.

	hr 1-4	hr 5-8	hr 9-20	hr 21-24
Ramp up	*0.2 x Daily Range*	*0.5 x Daily Range*	*0.2 x Daily Range*	*0.2 x Daily Range*
Ramp down	*0.5 x Daily Range*	*0.2 x Daily Range*	*0.2 x Daily Range*	*0.5 x Daily Range*

Table 2-8 Ramping Constraints for the Dispatchable Hydro Plants

Figure 2-4 and Figure 2-5 below compare a typical week of generation profile from the Grand Coulee Hydro Station, before and after the above hydro constraints are applied. An actual historical profile for Grand Coulee at the same week is plotted in Figure 2-6. From these three figures, we can see the updated approach produces more realistic hydro generation profile than the typical approach. Please note this is not a back-cast that tries to reproduce the historical profile. It is impossible to reproduce an identical hydro profile as it happened, without the complete operation data and constraint information available.

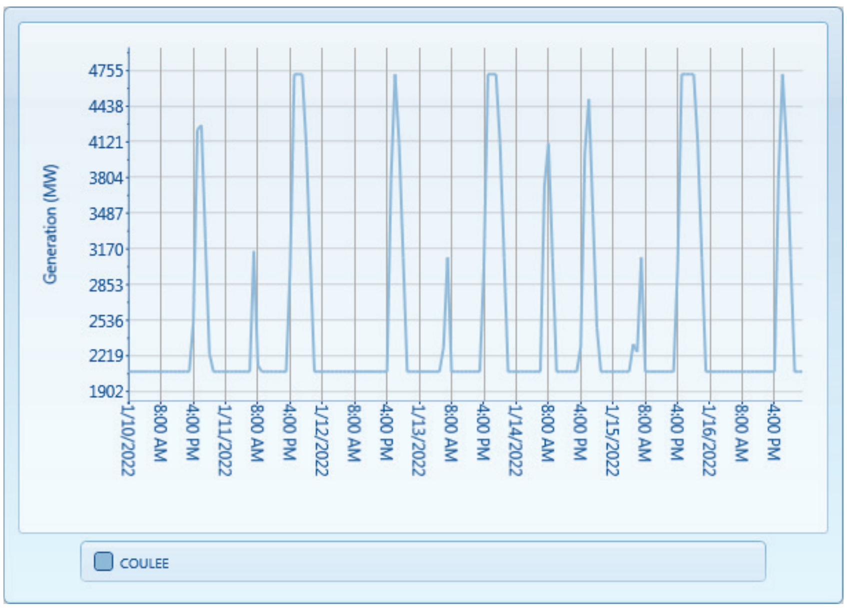

Figure 2-4 A Weekly Hydro Generation Profile before the constraints applied

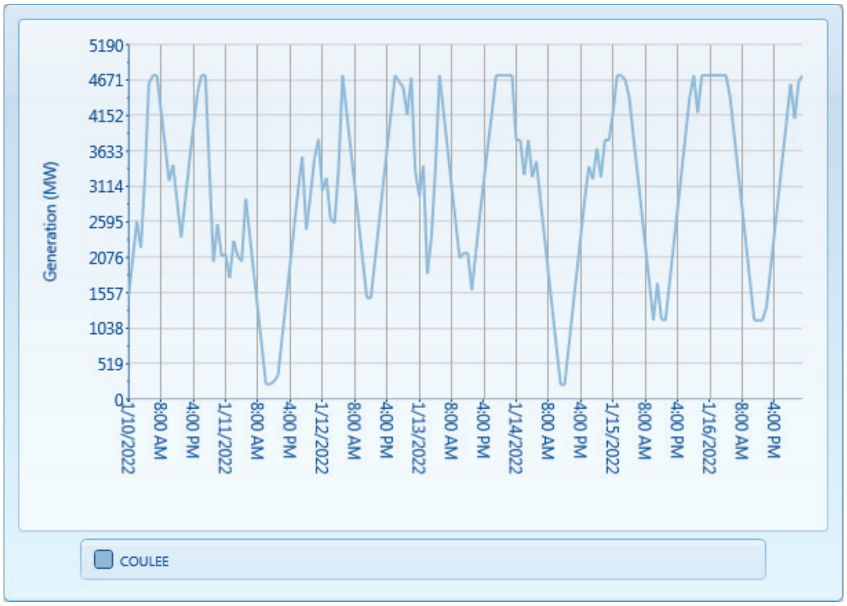

Figure 2-5 A Weekly Hydro Generation Profile after the constraints applied

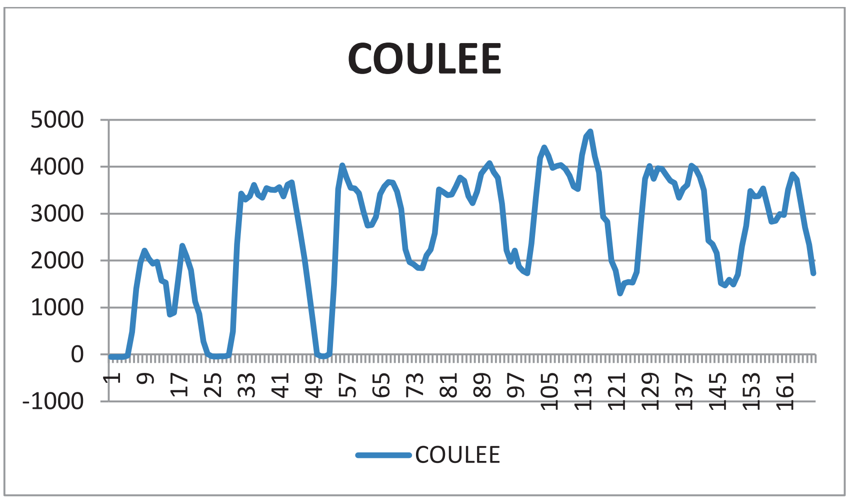

Figure 2-6 A Weekly Hydro Generation Profile from Historical Data

2.3.4 Gas Forecast

The gas price monthly profiles were originally from the WECC TEPPC for each gas hub. The gas forecast for the Malin Hub is updated to $5.14/MMBtu (all prices are based on the 2022 real dollar in this study) as an annual average for the study year 2022 according to EDF-RE. The other gas hub prices are scaled up or down according to their relative price ratio against the Malin hub in the 2022 TEPPC database. The annual average gas price for all focus areas are listed in Table 2-9. The original monthly price profiles are maintained as the same way in the original WECC TEPPC forecast.

State	Load Region	Price $/MMBtu
CA	SCE	5.23

State	Load Region	Price $/MMBtu
	PG&E_BAY	5.13
	PG&E_VLY	5.13
	SMUD	5.13
	TIDC	5.13
	IID	5.23
	LDWP	5.23
	SDGE	5.23
NV	NEVP	5.32
	SPP	6.54
OR	PACW	5.14
	PGN	5.37
WA	AVA	4.92
	BPA	5.18
	CHPD	4.92
	DOPD	4.92
	GCPD	4.92
	PSE	5.48
	SCL	5.48
	TPWR	5.48

Table 2-9 Annual Average Gas Price Forecast for This Study (2022$/MMBtu)

2.3.5 Ancillary Service Market Bidding Prices

In the ANL PSH study [3], an approach for assuming the AS capacity bid prices was used and described below. In that study, the bidding prices are only applied for the California generators. In this study, the generators in other areas are also assumed to have similar AS bidding prices based on the anticipation that their future AS markets will be running similarly to CAISO.

"The historical AS market clearing prices in year 2012 are analyzed. The analysis shows that the AS market clearing price is closely correlated with the energy market LMP that, in turn, is closely correlated with the regional load. The statistics and correlation of the CAISO NP15 LMP and AS clearing prices in year 2012 are shown in the following table.

From the analysis, the following approach is adopted to mimic the generator AS bidding price in the simulations.

1. *The hourly upward AS bidding prices follow the hourly California load profiles, and the hourly downward AS bidding prices follows the inverse of the hourly California load profiles;*
2. *The generators with a higher generation marginal cost will have lower AS bidding prices and the generators with a lower generation marginal cost will have higher AS bidding prices. The reason so doing is that the generators with higher*

generation marginal cost have lower energy profit margin, and the generators with lower generation marginal cost have higher energy profit margin.

3. *The final hourly AS bidding price for a generator is the normalized hourly AS bidding price profiles times the AS bidding price scaling factor. The normalized hourly AS bidding price profiles is the normalized hourly California load profile for the upward AS, and the inverse of the normalized hourly California load profile for the downward AS.*
4. *The generator AS bidding price scaling factor has a higher value for higher quality reserves.*
5. *Hydro generators and PSHs have fast ramp capability, and are assumed to provide the AS before the thermal generators."*

The AS bidding price scaling factors, proportional to the generator energy profit margin, by generator type and by AS type are shown in Table 2-10 below.

AS Bidding Price Scaling Factor by Generator Type ($/MW)						
Generator Type	**Non-Spin**	**Spin**	**Flex Dn**	**Flex Up**	**Reg Dn**	**Reg Up**
CC	3	9	15	15	30	30
Coal	5	15	35	35	60	60
CT	2	6	10	10		
DR	2	6	10	10		
Hydro	1	3	5	5	10	10
IC	2	6	10	10		
PSH	1	3	5	5	10	10
STEAM	2	6	10	10		

Table 2-10 AS Bidding Price Scaling Factor by Generator Type ($/MW)

2.3.6 LMS100 Replacement

In order to test the benefits and impacts from an equivalent thermal option built at the same location, a parallel analysis is performed with a set of equivalent sized LMS100 aero-derivative combustion turbines installed. Table 2-11 shows the LMS100 unit characteristics which are derived from some similar new generators proposed in the CPUC 2012 LTPP database[4]. It is assumed the maximum capacity of the LMS100 is exactly 100MW and therefore four LMS100 turbines are added in the LMS cases to match with the Swan Lake PSH project size.

Properties	**Value**	**Unit**
Max Capacity	100	MW
Min Stable Level	40	MW
Load Point 1	40	MW
Load Point 2	100	MW

[4] http://www.cpuc.ca.gov/PUC/energy/Procurement/LTPP/index_2012.htm

Properties	Value	Unit
Heat Rate 1	10500	BTU/kWh
Heat Rate 2	9191	BTU/kWh
VO&M Charge	4	$/MWh
Start Cost	3100	$
Min Up Time	2	hrs
Min Down Time	2	hrs
Max Ramp Up	17.14	MW/min.
Max Ramp Down	17.14	MW/min.
Maintenance Rate	4.53	%
Forced Outage Rate	5.82	%
Mean Time to Repair	55	hrs
Start Fuel Quantity	130	MMBTU

Table 2-11 LMS100 Unit Characteristics

2.4 Alternatives

The base case measures the total production cost savings and other benefits under the neutral conditions. In Phase 3 study, EDF-RE also identified two other alternatives to be tested in a similar way.

2.4.1 High Renewables

33% Renewable penetration is mandatory in California in year 2020. A greater RPS level, of 50%, is under discussion. Such a high level renewable penetration needs more flexible resources to back up the uncertainty and variability of the renewable generation. It is interesting to study a high RPS scenario and measure the Swan Lake PSH's benefits under this situation. Other than California, a couple of other states are assumed to fully meet their RPS target at the year 2022 in this alternative. A comparison of renewable penetration level between the base case and the high renewables alternative are listed in Table 2-12.

State	Base	High RPS
AZ	15%	15%
CA	33%	50%
CO	30%	30%
ID	16%	16%
MT	20%	20%
NM	20%	20%
NV	22%	25%
OR	22%	25%
UT	20%	20%
WA	23%	23%
WY	20%	20%

Table 2-12 Renewable Generation Percentage for Base Case and High RPS Alternative

2.4.2 High Gas Price

Back in 2012, the shale gas massive production dragged the gas price below $3/MMBTU. The long term gas forecast was also estimated at a very low level due to this effect. Since then, the technology and environmental concern of the shale gas fracking process has changed the optimistic view of shale gas production. The recent gas price forecasts from different agents are much higher than they were a couple of years ago. A high gas price alternative is studied for this reason. EDF-RE provided the high gas forecast for the Malin Hub as $5.76/MMbtu as the annual average for the study year 2022. The other Gas Hub prices are scaled up or down according to their price ratio against Malin hub in the 2022 TEPPC database.

3 Modeling Approaches

3.1 PLEXOS SCUC/ED algorithm

PLEXOS' Security Constrained Unit Commitment (SCUC) algorithm consists of two major logics: Unit Commitment using Mixed Integer Programming and Network Applications. The SCUC/ED simulation algorithm is illustrated in the following figure.

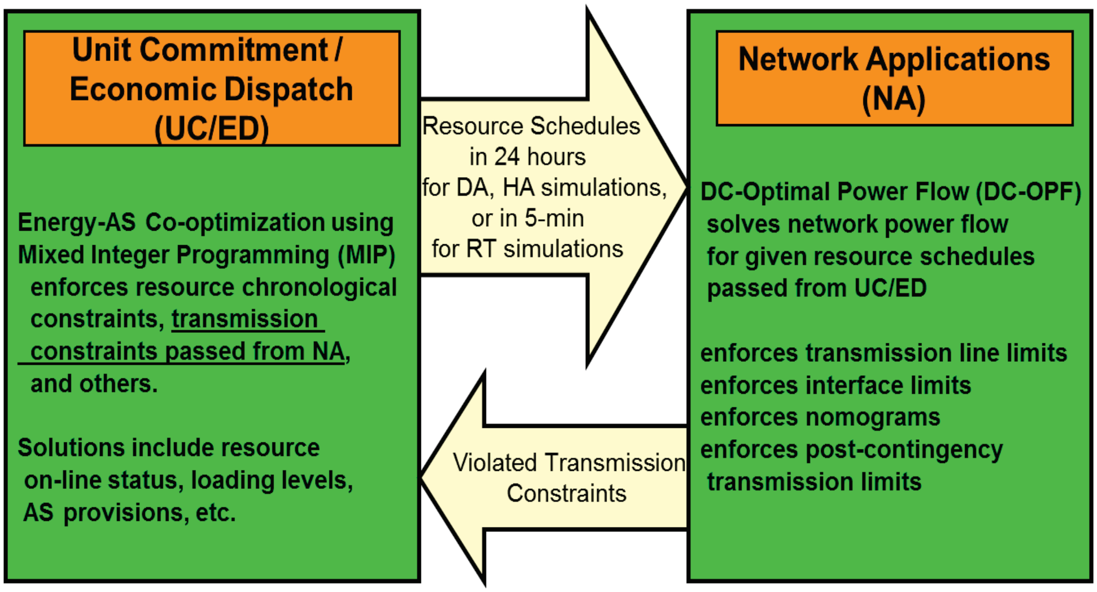

Figure 3-1 PLEXOS Security Constrained Unit Commitment and Economic Dispatch Algorithm

The unit commitment and economic dispatch (UC/ED) logic performs the Energy-AS co-optimization using Mixed Integer Programming enforcing all resource and operation constraints. The UC/ED logic commits and dispatches resources to balance the system energy demand and meet the system reserve requirements.

The resource schedules from the UC/ED are passed to the Network Applications logic. The Network Applications logic solves the DC-OPF to enforce the power flow limits and nomograms. The Network Applications logic also performs the contingency analysis if the contingencies are defined. If there are any transmission limit violations, these transmission limits are passed to the UC/ED logic for the re-run of UC/ED. The iteration continues until all transmission limit violations are resolved. Thus the co-optimization solution of Energy-AS-DC-OPF is reached.

The same algorithm for the SCUC/ED is used by many ISO market scheduling software (some ISO market scheduling software may use AC-OPF in the Network Applications).

One of the advantages of the MIP algorithm is its transparency. Any cost component or constraint in the MIP formula can be examined and explained.

The MIP mathematical formulation for the Energy-AS-DCOPF-PSH co-optimization can be illustrated by the following formula.

$$\min \sum_{t=1}^{T} \left\{ \sum_{k=1}^{K} \left[c_k^t \cdot g_k^t + sc_k^t \cdot (u_k^t - u_k^{t-1}) + \sum_{as=1}^{AS} asc_{k,as}^t \cdot as_{k,as}^t \right] \right\}$$

Subject to

$$\sum_{k=1}^{K} g_k^t + \boldsymbol{eff_g} \cdot \boldsymbol{g_{psh}^t} = \sum_{l=1}^{L} load_l^t + \boldsymbol{pump_{psh}^t} + \sum_{m=1}^{M} loss_m^t \quad \forall t,$$

(Energy Balance Constraint)

$$\boldsymbol{sto^t} = \boldsymbol{sto^{t-1}} - \boldsymbol{g_{psh}^t} + \boldsymbol{eff_p} \cdot \boldsymbol{pump_{psh}^t} \ \forall t,$$

(PSH Storage Balance Constraint)

$$\sum_{k=1}^{K} as_{k,as}^t \geq as_{as}^{t,min} \quad \forall t,\ as,$$

(AS as Requirement Constraints)

$$as_{k,as}^{t,min} \leq as_{k,as}^t \leq as_{k,as}^{t,max} \quad \forall t,\ as, k,$$

(Generator k AS capacity Constraints)

$$g_k^{t,min} \cdot u_k^t \leq g_k^t \pm \sum_{as=1}^{AS} as_{k,as}^t \leq g_k^{t,max} \cdot u_k^t \quad \forall t, k,$$

(Generation and AS Capacity Constraints)

$$g_k^t - g_k^{t-1} \pm \sum_{as=1}^{AS} as_{k,as}^t \leq ramp_k^{t,max} \cdot u_k^t \quad \forall t, k,$$

(Generation and AS Ramp Capacity Constraint)

$$f_j^{t,min} \leq f_j^t = \sum_{k=1}^{K} PTDF_j^{c,k} \cdot (g_k^t - load_k^t) \leq f_j^{t,max} \quad \forall t, j, c$$

(Transmission line j Limit Constraints)

$$i_j^{c,t,min} \leq \sum_{j \in i} I_{line}{}_j^i \cdot f_j^{c,t} \leq i_j^{c,t,max} \quad \forall t, i, c$$

(Interface i Limit Constraints)

Generator Chronological Constraints

Resource Constraints

User-Defined Constraints

Where

g_k^t - Generation from generator k at interval t;

c_k^t - Generation cost of generator k at interval t;

u_k^t - Unit commitment status of generator k at interval t; 1=on-line, 0=off-line

sc_k^t - Startup / shut down cost of generator k at interval t;

$as_{k,as}^t$ - AS provision from generator k to AS as at interval t;

$asc_{k,as}^t$ - AS provision cost of generator k to AS as at interval t;

$\boldsymbol{eff_g}$ **-** PSH generating efficiency;

$\boldsymbol{eff_p}$ **-** PSH pumping efficiency;

$\boldsymbol{g_{psh}^t}$ **-** PSH generation at interval t;

$\boldsymbol{pump_{psh}^t}$ **-** PSH pump at interval t;

$load_l^t$ - Load at bus l at interval t;

$loss_m^t$ - Transmission losses of line m at interval t;

$g_k^{t,min}$ - Min capacity of generator k at interval t;

$g_k^{t,max}$ - Max capacity of generation k at interval t;

$ramp_k^{t,max}$ - Max ramp up / down rate;

$as_{as}^{t,min}$ - Min AS requirement for AS as at interval t;

$as_{k,as}^{t,min}$ - Min AS provision of generator k for AS as at interval t;

$as_{k,as}^{t,max}$ - Max AS provision of generator k for AS as at interval t;

$PTDF_j^{c,k}$ - Power Transfer Distribution Factor of bus k to transmission line j for post-contingency network c ($c = 0$ is the pre-contingency network);

$f_j^{c,t}$ - Line flow in transmission line j at interval t for post-contingency network c;

$f_j^{c,t,min}$ - Min line flow of transmission line j at interval t for post-contingency network c;

$f_j^{c,t,max}$ - Max line flow of transmission line j at interval t for post-contingency network c;

$I_{line}{}_j^i$ - Line coefficient of transmission line j in interface;

$i_j^{c,t,min}$ - Min interface flow of interface i at interval t for post-contingency network c;

$i_j^{c,t,max}$ - Max interface flow of interface i at interval t for post- contingency network c;

The PSH pumping and generating are incorporated in Constraints "(Energy Balance Constraint)" and "(PSH Storage Balance Constraint)". By doing so, the PSH operation is co-optimized with other variables: energy, ancillary services, power flow, etc. This formula is different from other legacy PSH dispatch algorithm: generating a thermal cost curve, then dispatching PSH against the thermal cost curve, and finally re-dispatching thermal generators with the PSH operation frozen. This legacy PSH dispatch algorithm assumes that PSH is a price-taker facility and its operation does not impact the system prices. Actually, PSH can provide energy and ancillary service simultaneously and the market energy and AS prices will be impacted by the PSH operation.

3.2 Three-stage DA-HA-RT Sequential Simulations

As the intermittent resources, the renewable generators place a lot of challenges to the power system planning and operation due to their variability and uncertainty in nature. One of the questions that the power industry needs to answer is: what is the impact of the sub-hourly renewable generation variability and uncertainty to the system operation and how to quantify it?

The three-stage DA-HA-RT sequential simulation framework used in the ANL PSH study and this study is important to evaluate the PSH facilities based on the following facts:

1. This is how the market (or portfolio) operates today: DA and HA (intra-day) SCUC decisions are based on the forecasts of load and renewable generations; sub-hourly RT SCED is to meet the actual load with the actual renewable generation incorporated.
2. The sub-hourly RT solutions can be significantly different from the DA/HA solutions. This is proven by the ANL study and this study, as shown in Section 4.
3. A DA only simulation cannot capture the full dynamic details in a high renewable environment and therefore cannot quantify how PSH accommodates the load and renewable uncertainty and variability.

Figure 3-2 through Figure 3-5 plot an example of the forecast load, solar generation, wind generation and net load (*calculated as forecast load –solar generation – wind generation*) for the PG&E Valley area in this study. This is a typical week profile in January 2022, with the horizontal axis representing the 5-minute intervals in that week. By comparing the profiles in the DA, HA forecasts and RT "actual", it can be seen they differ quite a lot in some hours due to the forecast error and variability. The figures shown here are the regional aggregation of bus level profiles and therefore some variability already cancelled out during the aggregation. At the individual bus, the variability might be even higher.

Traditionally the generation asset evaluation is performed only in a DA-like market environment assuming the DA and RT markets would have similar load condition and therefore the generation pattern in the system will not deviate too much. As shown in these figures below, this is not true when the renewable penetration level in the system is high. In a typical market operation, quite a lot of generators in the system have to have their unit commitment decisions made in the DA market or HA market because of their less flexibility during the startup and shutdown. That means they cannot use their full capacity potential to react the net load deviation in the RT market. On the contrary, the flexible resources usually have full potential in the RT market to compensate the variability from the net load. If only the DA market is simulated, the value of the flexible resources will be under-estimated.

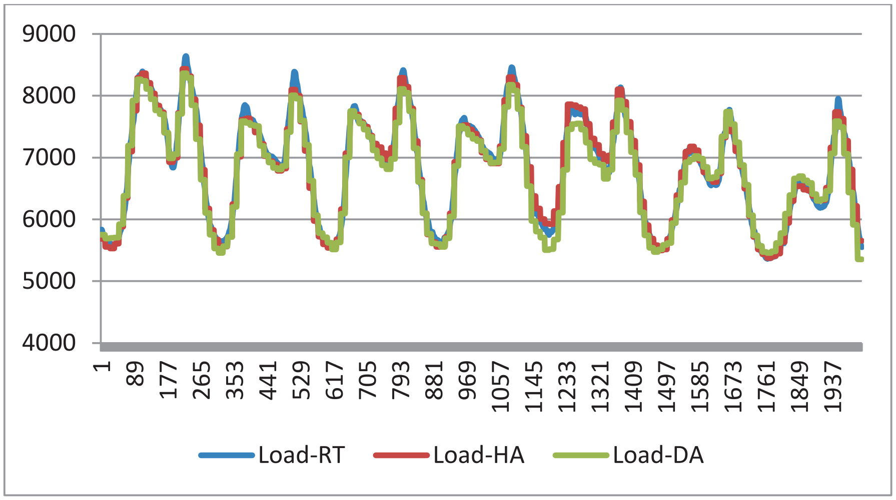

Figure 3-2 DA, HA and RT Load Forecast in a Typical Week for PG&E_Vly in Jan 2022 (MW)

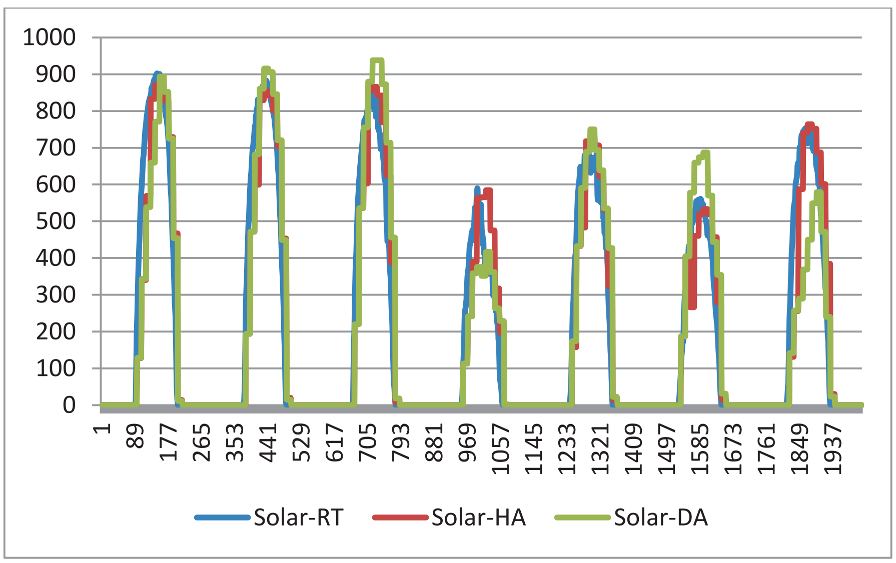

Figure 3-3 DA, HA and RT Solar Generation in a Typical Week for PG&E_Vly in Jan 2022 (MW)

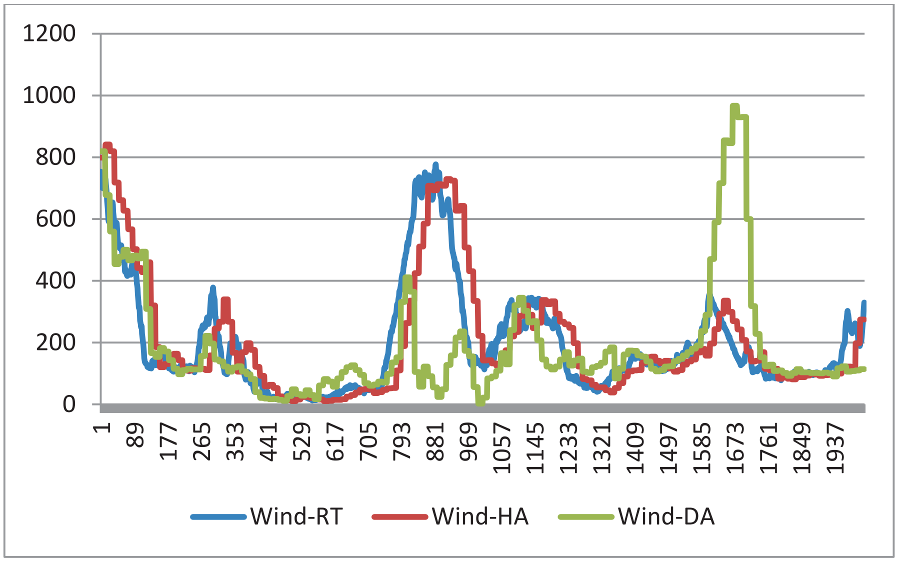

Figure 3-4 DA, HA and RT Wind Generation in a Typical Week for PG&E_Vly in Jan 2022 (MW)

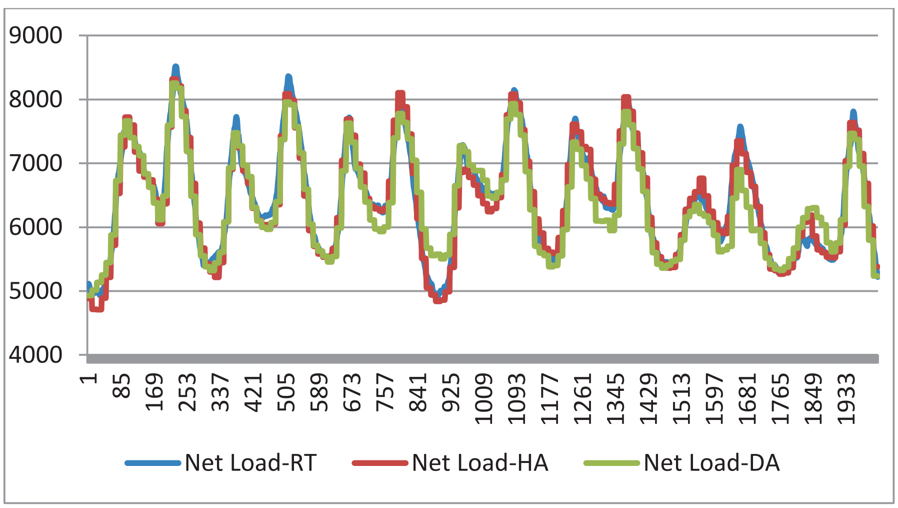

Figure 3-5 DA, HA and RT Net Load in a Typical Week for PG&E_Vly in Jan 2022 (MW)

PLEXOS is capable of simulating power markets at a sub-hourly interval. The three-stage DA-HA-RT sequential simulation approach using PLEXOS is shown in Figure 3-6 and described as follows.

- **DA simulation mimics the DA SCUC/SCED**
    - Day-ahead forecasted load/wind/solar generation time series are used;
    - The SCUC/ED optimization window is 24 hours at hourly interval;
    - The transmission network is modeled at the nodal level;
    - The contingency, flexibility up/down, regulation up/down reserves are modeled.
- **HA simulation mimics the intra-day SCUC/SCED**
    - The 4-hour-ahead forecasted wind / solar generation time series are used;
    - The hour-ahead forecasted load time series are used;

- The SCUC/ED optimization window is 24 hours at hourly interval;
- The unit commitment patterns from the DA simulation are frozen for generators with Min Up/Down Time greater than 4 hours;
- The transmission network is modeled at the nodal level;
- The contingency, flexibility up/down, regulation up/down reserves are modeled.

- **RT simulation mimics the 5-min real-time SCED**
    - The "actual" 5-min load/wind/solar generation time series are used;
    - The SCED optimization window is twelve 5-min plus 12 look-ahead with 2 hours interval;
    - The unit commitment patterns from the HA simulation are frozen;
    - The transmission network is modeled at the nodal level;
    - The contingency, regulation up/down reserves are modeled. However, the flexibility up/down reserves are not modeled. The implication is that the capacity held in the HA simulation for the flexibility reserves is deployed to cover the load and renewable generation variability and uncertainty at the 5-min interval;
    - CT with max capacity less than 100MW could be committed or de-committed in the 5-min RT simulation.

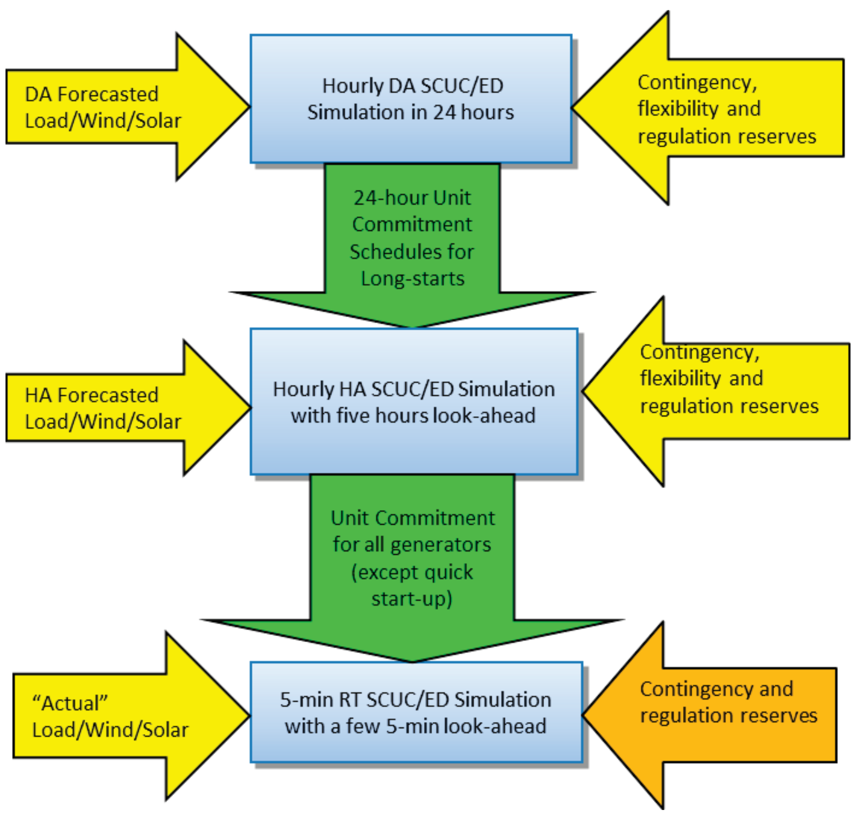

Figure 3-6 DA-HA-RT Three-stage Sequential Simulations

3.3 PSH Storage Modeling in Three-stage Sequential Simulations

In the DA simulation, the SCUC/ED is performed in a 24-hour window. The PSHs are dispatched by PLEXOS SCUC/ED according to the formulation in Section 3.1 PLEXOS SCUC/ED algorithm. The storage volume of a PSH at the end of the 24-hour optimization window is constrained to the storage volume at the beginning of the optimization window. A penalty price of $1,000/MWh is applied to the storage volume constraints.

In the HA simulation, the SCUC/ED is performed in a 24-hour window. The PSHs are re-dispatched in the HA simulation according to the formulation in Section 3.1 PLEXOS SCUC/ED algorithm. The storage volume of a PSH at the end of the 24-hour optimization window is constrained to the storage volume at the beginning of the optimization window. A penalty price of $1,000/MWh is applied to the storage volume constraints.

In the 5-min RT simulation, the SCUC/ED is performed in a twelve 5-minutes plus 24-hour look-ahead window. The simulation solution in the first twelve 5-minutes is saved; then the SCUC/ED is performed for the next twelve 5-minutes in a twelve 5-minutes plus 24-hour look-ahead window, and so on. The PSHs are re-dispatched from the RT simulation according to the formulation in Section 3.1 PLEXOS SCUC/ED algorithm. The storage volume of a PSH at the end of the optimization window is constrained to the storage volume from the HA simulation. A penalty price of $1,000/MWh is applied to the storage volume constraints.

3.4 Scope of Simulations

The simulated and analyzed cases are listed in the following table.

Group	Scenario[5]	Evaluated Resources	RPS % in California	Gas Price
1: Base RPS and Base Gas Price	A base	N/A	33%	Base
	A	Swan Lake 393.3 MW	33%	Base
	D-2	LMS100 400 MW	33%	Base
2: Base RPS and High Gas Price	E-1 base	N/A	33%	High
	E-1	Swan Lake 393.3 MW	33%	High
	E-2	LMS100 400 MW	33%	High
3: High RPS and Base Gas Price	C base	N/A	50%	Base
	C	Swan Lake 393.3 MW	50%	Base

Table 3-1 Simulated and Analyzed Cases in Phase 3

The eight scenarios can be separated into three groups.

Group 1: “Base RPS and Base Gas Price” consists of Scenarios “A-base”, “A” and “D-2” with 33% RPS in California and base gas prices; Group 2: “High RPS and Base Gas Price” consists of Scenarios “C-base” and “C” with 50% RPS in California and base gas prices;

[5] The Scenario IDs are used to match the simulation scenario IDs in the Scope of Work for Phase 3.

Group 3: “Base RPS and High Gas Price” consists of Scenarios “E-1-base”, “E-1” and “E-2” with 33% RPS in California and high gas price.

For each group, the WI footprint is simulated with the associated assumptions of RPS and gas prices. Then for each scenario in the group, the DA-HA-5-min RT sequential simulation is performed for the Focused Regions with the intertie flows frozen between the Focused Regions and the rest of WI.

The following table shows the simulation footprint for the WI system and the Focused Regions.

Model System	WI	Focused Regions
Load Regions	39	21
Buses	over 17,000	over 8,800
Transmission Lines	over 22,000	over 11,000
Interfaces	91	55
Generator	over 3,700	0ver 2,200
Existing FS PSHs	8	4
Network Representation	Nodal	Nodal
DA Simulation Step	24-hour	24-hour
HA Simulation Step	N/A	24-hour
RT Simulation Step	N/A	12 5-minutes plus 24-hour look-ahead

Table 3-2 Simulation Details for WI and Focused Regions

4 Simulation Result Analyses

This section will present the simulation solutions and analyze the solutions. The solutions and analyses presented in this section include

1. Swan Lake PSH's impact to the production cost for the focused regions and the major BAs in the focused regions,
2. Swan Lake operation and net revenue and comparison with LMS100,
3. Swan Lake PSH's impact to the generation and generation cost by generator type,
4. Swan Lake PSH's impact to the renewable curtailment in the major BAs in the focused regions,
5. Swan Lake PSH's impact to the emission production in the major BAs in the focused regions, and
6. Swan Lake PSH's impact to the thermal generator cycling in the major BAs in the focused regions.

All the results mentioned here are based on the annual total for the modeled study year 2022. The cost and revenue values are based on the 2022 real US dollar.

4.1 Net Interchange from the Interties

For each group of cases in Table 3-1 Simulated and Analyzed Cases in Phase 3, the entire West Interconnection is simulated to produce the intertie flows between the focused regions and the rest of the WI. The intertie flows are frozen in the 3-stage sequential simulation for the focused regions. In the comparisons of Swan Lake PSH or other evaluated resources, the intertie flows are the same and their economic impacts are cancelled out. Therefore the analyses will ignore the economic impacts of these intertie flows.

4.2 Production Cost in Focused Regions

The production cost reduction is the most important index to measure the system level benefit with Swan Lake PSH installed. The production cost is calculated as

$$Prod\ Cost = \sum_{g} (Fuel\ Cost + VO\&M\ Cost + Start\ up\ \&\ Shunt\ down\ Cost + Emission\ Cost) \quad g\ is\ generator\ 1, 2, 3, \ldots.$$

Since the intertie flows between the focused regions and the rest of WI are the same in the cases of the same group and cancelled out in the comparisons of the cases, the production cost does not include the intertie flow costs and revenues.

4.2.1 *Swan Lake PSH's Impact to Production Cost in Case of Base RPS and Base Gas Price*

The following chart presents the production cost from the 3-stage sequential simulations in the focused regions in the cases of base RPS and base gas price with Swan Lake PSH or 400MW of LMS100 gas turbines.

It can be observed that

1. The production cost in the 5-minute real-time (RT) simulation is much higher than the hourly Day-ahead (DA) or Hour-ahead (HA) simulations due to the gas turbine commitment and other thermal generator cycling from the RT simulations,
2. With Swan Lake PSH, the total production cost from the RT simulation is reduced by 36 million dollar per year (=6,604 – 6,568) for the focused regions,
3. With the same capacity of LMS100, the total production cost from the RT simulation is reduced insignificantly by 4 million dollars per year (=6,604 – 6,600).

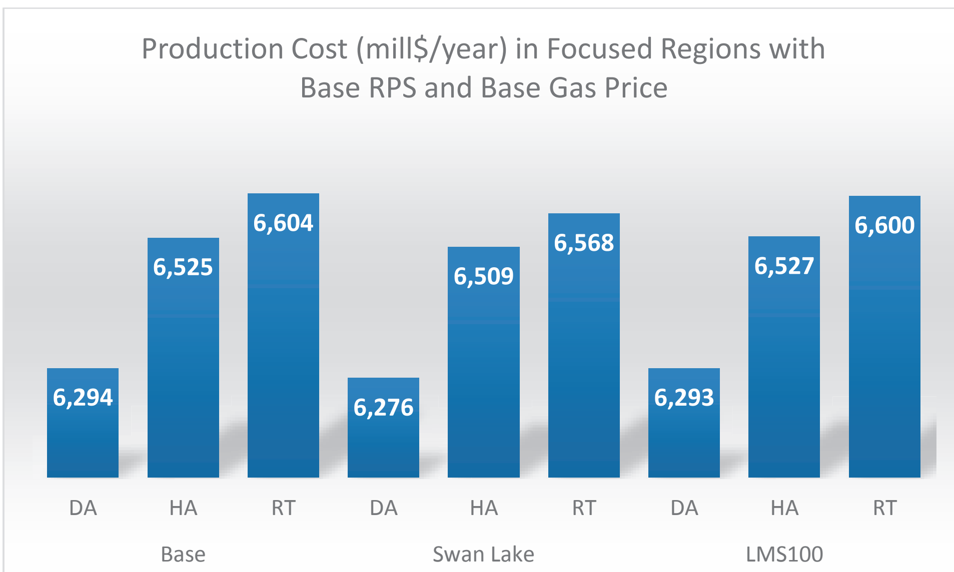

Figure 4-1 Production Cost Comparison (mill$/year) in the Focused Regions with the Base RPS and Base Gas Price

The following table shows the production cost for the major BAs in the focused regions with Swan Lake PSH or LMS100 in the cases of base RPS and base gas price. It can be noticed that almost all major BA benefits from Swan Lake PSH but CAISO is a major beneficiary with 26 million dollars saving per year (=4,374 – 4,348) while there is no major BA with production cost increased. However, with 400 MW of LMS100, BPA production cost is increased by 20 million dollars while the CAISO production cost is reduced by 16 million dollars. This bi-directional impact cannot be indicators of a loser or a winner since the BA interchange cost and revenue are not included in the BA production costs.

Production Cost (mill$/year) and Production Cost Reduction (mill$/year) with Base RPS and Base Gas Price															
	Production Cost (mill$/year)									Production Cost Reduction (mill$/year)					
Evaluated Resource	**Base**			**Swan Lake**			**LMS100**			**Swan Lake - Base**			**LMS100 - Base**		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	6,294	6,525	6,604	6,276	6,509	6,568	6,293	6,527	6,600	18	16	35	0	(2)	4
PacifiCorp	247	249	249	247	248	248	247	249	248	0	0	1	0	(0)	0
PGE	73	78	77	73	78	77	73	78	78	0	1	1	0	(0)	(0)
Avista Corp	30	35	33	30	35	33	30	34	32	0	(0)	0	(0)	1	1
Puget Sound	159	159	160	159	159	159	159	159	160	0	0	1	(0)	(0)	0
PG&E	1,652	1,710	1,740	1,647	1,707	1,730	1,652	1,711	1,735	5	3	11	1	(2)	6
SDG&E	671	697	689	670	695	686	671	696	688	1	2	4	0	1	2
SCE	1,891	1,906	1,944	1,884	1,899	1,932	1,889	1,905	1,937	7	7	12	2	2	7
LADWP	239	258	265	238	258	264	239	258	262	1	(1)	1	(0)	(0)	2
SMUD	248	241	253	248	241	252	249	242	252	(0)	(0)	1	(0)	(0)	1
BPA	398	419	407	394	418	406	401	423	426	4	1	1	(3)	(4)	(20)
CAISO	4,214	4,313	4,374	4,201	4,301	4,348	4,211	4,313	4,360	12	13	26	3	1	15

Table 4-1 Production Cost (mill$/year) and Production Cost Reduction (mill$/year) with Base RPS and Base Gas Price

4.2.2 Swan Lake PSH's Impact to Production Cost in Case of Base RPS and High Gas Price

The following chart presents the total production cost from the 3-stage sequential simulations in the focused regions in the cases of base RPS and High gas price with Swan Lake PSH or the 400MW of LMS100 gas turbines.

It can be observed that

1. The production cost in the 5-minute real-time (RT) simulation is much higher than the hourly Day-ahead (DA) or Hour-ahead (HA) simulations due to the gas turbine commitment and other thermal generator cycling from the RT simulations,
2. With Swan Lake PSH, the total production cost from the RT simulation is reduced by 37 million dollar per year (=7,124 – 7,087) for the focused regions,
3. With the same capacity of LMS100, the total production cost from the RT simulation is reduced insignificantly by 11 million dollars per year (=7,124 – 7,113).

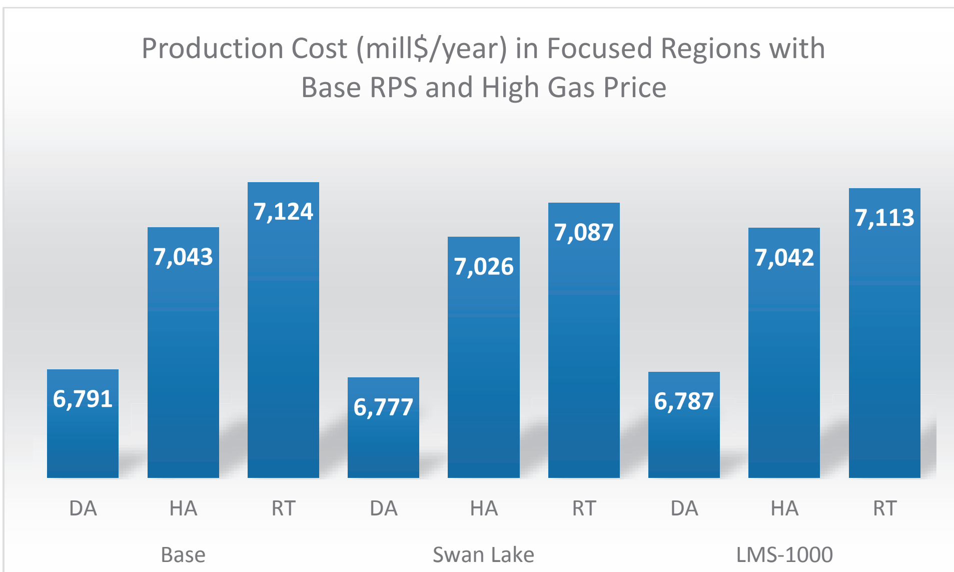

Figure 4-2 Production Cost Comparison (mill$/year) in the Focused Regions with Base RPS and High Gas Price

The following table shows the production cost for the major BAs in the focused regions with Swan Lake PSH or LMS100 in the cases of base RPS and high gas price. It can be noticed that almost all major BA benefits from Swan Lake PSH but CAISO is a major beneficiary with 28 million dollars saving per year (=4,753 – 4,725). However, with 400 MW of LMS100, BPA production cost is increased by 21 million dollars while the CAISO production cost is reduced by 22 million dollars. Again, this bi-directional impacts cannot be indicators of a loser or a winner since the BA interchange cost and revenue are not included in the BA production costs.

Production Cost (mill$/year) and Production Cost Reduction (mill$/year) with Base RPS and High Gas Price															
	Production Cost (mill$/year)									Production Cost Reduction (mill$/year)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	6,791	7,043	7,124	6,777	7,026	7,087	6,787	7,042	7,113	15	17	37	4	1	11
PacifiCorp	269	270	270	269	270	269	269	270	270	(0)	(0)	1	0	(0)	0
PGE	80	85	84	80	85	84	80	85	84	(0)	0	0	(0)	1	1
Avista Corp	32	38	35	32	38	36	31	37	35	(0)	(0)	(0)	0	1	1
Puget Sound	173	173	174	173	173	173	173	173	173	(0)	(0)	0	(0)	(0)	0
PG&E	1,773	1,838	1,869	1,769	1,830	1,854	1,771	1,836	1,859	5	8	15	2	2	10
SDG&E	736	763	754	734	762	752	735	762	752	2	1	2	1	1	2
SCE	2,076	2,090	2,129	2,070	2,084	2,119	2,073	2,088	2,120	6	6	11	3	1	9
LADWP	247	265	272	248	265	271	247	265	270	(1)	0	2	(0)	0	2
SMUD	266	265	278	267	265	277	266	266	277	(0)	0	1	0	(0)	1
BPA	415	439	426	414	439	425	420	445	447	1	1	1	(4)	(5)	(21)
CAISO	4,585	4,691	4,753	4,573	4,677	4,725	4,579	4,686	4,731	12	14	28	7	5	22

Table 4-2 Production Cost (mill$/year) and Production Cost Reduction (mill$/year) with Base RPS and High Gas Price

4.2.3 Swan Lake PSH's Impact to Production Cost in Case of High RPS and Base Gas Price

The following chart presents the total production cost from the 3-stage sequential simulations in the focused regions in the cases of High RPS and base gas price with Swan Lake PSH.

It can be observed that

1. The production cost in the 5-minute real-time (RT) simulation is much higher than the hourly Day-ahead (DA) or Hour-ahead (HA) simulations due to the gas turbine commitment and other thermal generator cycling from the RT simulations,
2. With Swan Lake PSH, the total production cost from the RT simulation is reduced by 52 million dollar per year (=6,317 – 6,263) for the focused regions.

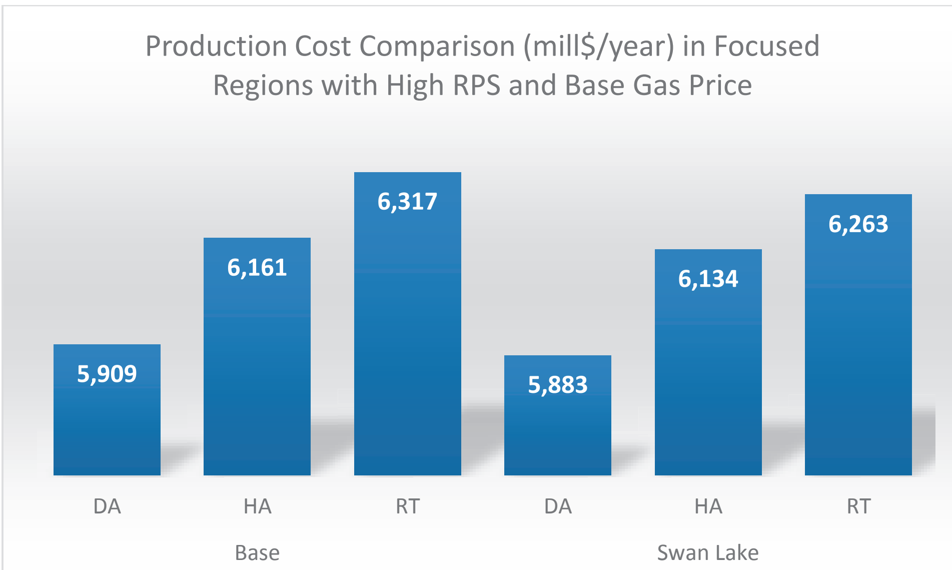

Figure 4-3 Production Cost Comparison (mill$/year) in the Focused Regions with High RPS and Base Gas Price

The following table shows the production cost for the major BAs in the focused regions with Swan Lake PSH in the cases of High RPS and base gas price. It can be noticed that all major BA benefits from Swan Lake PSH but CAISO is a major beneficiary with 33 million dollars saving per year (=4,156 – 4,124).

Comparing with the production cost reductions in the cases of base RPS and base or high gas price, the magnitude of the production cost reduction is bigger in the case of the high RPS and base gas price. This indicates that PSH demonstrates more benefit to the higher renewable penetration levels.

Production Cost (mill$/year) and Production Cost Reduction (mill$/year) with High RPS and Base Gas Price									
	Production Cost (mill$/year)						Production Cost Reduction (mill$/year)		
Evaluated Resource	Base			Swan Lake			Swan Lake - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	5,909	6,161	6,317	5,883	6,134	6,263	26	27	53
PacifiCorp	240	242	244	240	242	243	1	0	1
PGE	70	74	73	70	74	72	(0)	0	0
Avista Corp	25	29	29	25	29	28	(0)	(0)	1
Puget Sound	155	156	158	155	156	157	0	1	1
PG&E	1,515	1,587	1,643	1,509	1,578	1,624	6	8	19
SDG&E	637	666	658	636	664	655	1	1	2
SCE	1,791	1,805	1,856	1,781	1,798	1,845	10	7	11
LADWP	221	240	262	221	239	257	0	1	5
SMUD	228	230	244	227	230	243	1	0	1
BPA	375	394	384	370	392	381	5	2	3
CAISO	3,943	4,058	4,156	3,927	4,041	4,124	16	17	33

Table 4-3 Production Cost (mill$/year) and Production Cost Reduction (mill$/year) with High RPS and Base Gas Price

4.3 Swan Lake PSH Operation and Net Revenue

Assuming Swan Lake PSH is operated as an independent power producer, it will receive revenue from the generation and AS provisions, and will pay for the pumping cost. This section presents Swan Lake PSH net revenue in the different cases.

Swan Lake PSH $Net\ Revenue$ is calculated as

$$Net\ Revenue = Energy\ Revenue + AS\ Revenue - Pump\ Cost$$

$$where,$$

$$Energy\ Revenue = \sum_t LMP_t \times Generation_t \qquad t = hour\ 1, 2, 3, \ldots.$$

$$AS\ Revenue = \sum_{s,t} Reserve\ Price_{s,t} \times Reserve\ Provision_{s,t} \qquad t = hour\ 1, 2, 3, \ldots.$$

s $represents\ different\ AS\ markets, like\ spin, non-spin, flex\ up, flex\ down, regup, regdn, etc.$

$$Pump\ Cost = \sum_t LMP_t \times Pump\ Load_t \qquad t = hour\ 1, 2, 3, \ldots.$$

4.3.1 Swan Lake PSH Operation and Net Revenue in Case of Base RPS and Base Gas Price

The following table shows Swan Lake PSH generation, AS provisions and pumping energy in the case of base RPS and base gas price.

The capacity factor of Swan Lake PSH from the RT simulation in this case is 33% ($= \frac{1,134,000}{391.8 \times 8760}$). The net revenue from the RT simulation is 39 million dollars per year (= 50 – 25 + 10). This net revenue yields Swan Lake PSH value 100 $/kw-year ($= \frac{39,000}{391.8}$).

The capacity factor of 400 MW of LMS100 from the RT simulation in this case is 7.9% ($= \frac{277,000}{400 \times 8760}$). The net revenue is 26 million dollars per year (=26 – 0 + 0). This net revenue yields the 400MW of LMS100 value 67 $/kw-year ($= \frac{26,000}{400}$).

Swan Lake or LMS100 Operation and Revenue with Base RPS and Base Gas Price								
Evaluated Resource	**Resource Operation (GWh)**				**Resource Revenue (mill$/year)**			
		DA	**HA**	**RT**		**DA**	**HA**	**RT**
Swan Lake	Generation	1,226	1,217	1,134	Energy Revenue	40	40	55
	Pump Load	1,601	1,590	1,477	Pump Cost	(13)	(14)	(25)
	AS Upward Provision	404	404	549	AS Revenue	5	5	10
	AS Downward Provision	438	433	281	Total	32	30	39
					$/kW-Year	82	77	100
LMS100	Generation	59	63	277	Energy Revenue	3	3	26
	Pump Load	0	0	0	Pump Cost	0	0	0
	AS Upward Provision	21	21	35	AS Revenue	0	0	0
	AS Downward Provision	48	59	45	Total	3	4	26
					$/kW-Year	9	9	67

Table 4-4 Evaluated Resource Operation and Revenue with Base RPS and Base Gas Price

Swan Lake PSH is designated to provide AS to PacifiCorp and CAISO. And the LMS100 is designated to provide AS to CAISO. The following table shows the AS provisions to PacifiCorp and CAISO from Swan Lake PSH or 400MW of LMS100. It is noticed that Swan Lake PSH provides majority AS to PacifiCorp and small amount AS to CAISO, most to the downward AS. The reduction of the AS provisions from Swan Lake PSH to CAISO, as opposed to the Phases 1 and 2 study results, is due to the 1.325 GW energy storage facilities modeled in the Phase 3 simulations.

The AS provisions from LMS100 to CAISO is insignificant due to the same fact of 1.325GW energy storage facilities modeled in the Phase 3 simulations.

Swan Lake or LMS100 AS Provision (GWh) and Revenue (k$) by BA with Base RPS and Base Gas Price												
Evaluated Resource	**Swan Lake**						**LMS100**					
BA	**PacifiCorp**			**CAISO**			**PacifiCorp**			**CAISO**		
AS Product	**DA**	**HA**	**RT**	**DA**	**HA**	**RT**	**DA**	**HA**	**RT**	**DA**	**HA**	**RT**
Regulation-Up (GWh)	235	232	356	0	0	0	0	0	0	0	0	0

Regulation-Down (GWh)	302	301	279	25	22	1	0	0	0	0	0	0
Flex Up (GWh)	75	78	0	3	2	0	0	0	0	1	0	0
Flex Down (GWh)	94	93	0	19	17	0	0	0	0	0	0	0
Spin (GWh)	1	0	2	1	0	3	0	0	0	0	0	1
Non-Spin (GWh)	76	77	136	14	14	51	0	0	0	16	20	25
Total AS Revenue (k$)	**4,510**	**4,397**	**9,474**	**209**	**185**	**108**	**0**	**0**	**0**	**52**	**60**	**54**

Table 4-5 Swan Lake or LMS100 AS Provision (GWh) and Revenue (k$) by BA with Base RPS and Base Gas Price

4.3.2 Swan Lake PSH Operation and Net Revenue in Case of Base RPS and High Gas Price

The following table shows Swan Lake PSH generation, AS provisions and pumping energy in the case of base RPS and High gas price. The capacity factor of Swan Lake PSH from the RT simulation in this case is 32% ($= \frac{1{,}108{,}000}{391.8 \times 8760}$). The net revenue from the RT simulation is 41 million dollars per year (= 58 – 26 + 10). This net revenue yields the Swan Lake PSH value 105 $/kw-year ($= \frac{41{,}000}{391.8}$).

The capacity factor of 400 MW of LMS100 from the RT simulation in this case is 7.6% ($= \frac{267{,}000}{400 \times 8760}$). The net revenue is 27 million dollars per year (=27 – 0 + 0). This net revenue yields the 400MW of LMS100 value 69 $/kw-year ($= \frac{27{,}000}{400}$).

Swan Lake or LMS100 Operation and Revenue with Base RPS and High Gas Price								
Evaluated Resource	Resource Operation (GWh)				Resource Revenue (mill$/year)			
		DA	HA	RT		DA	HA	RT
Swan Lake	Generation	1,221	1,212	1,108	Pool Revenue	43	42	58
	Pump Load	1,594	1,584	1,444	Pump Cost	(13)	(15)	(26)
	AS Upward Provision	420	442	571	AS Revenue	5	5	10
	AS Downward Provision	455	455	268	Total	34	32	41
					$/kW-Year	87	81	105
LMS100	Generation	59	62	267	Pool Revenue	4	4	27
	Pump Load	0	0	0	Pump Cost	0	0	0
	AS Upward Provision	10	13	38	AS Revenue	0	0	0

	AS Downward Provision	33	41	44	Total	4	4	27
					$/kW-Year	9	9	69

Table 4-6 Evaluated Resource Operation and Revenue with Base RPS and High Gas Price

Swan Lake PSH is designated to provide AS to PacifiCorp and CAISO. And the LMS100 is designated to provide AS to CAISO. The following table shows the AS provisions to PacifiCorp and CAISO from Swan Lake PSH or 400MW of LMS100. Again, it is noticed that Swan Lake PSH provides majority AS to PacifiCorp and small amount AS to CAISO, most to the downward AS. The reduction of the AS provisions from Swan Lake PSH to CAISO, as opposed to the Phases 1 and 2 study results, is due to the 1.325 GW energy storage facilities modeled in the Phase 3 simulations.

The AS provisions from LMS100 to CAISO is insignificant due to the same fact of 1.325GW energy storage facilities modeled in the Phase 3 simulations.

Swan Lake or LMS100 AS Provision (GWh) and Revenue (k$) by BA with Base RPS and High Gas Price												
Evaluated Resource	**Swan Lake**						**LMS100**					
BA	**PacifiCorp**			**CAISO**			**PacifiCorp**			**CAISO**		
AS Product	**DA**	**HA**	**RT**	**DA**	**HA**	**RT**	**DA**	**HA**	**RT**	**DA**	**HA**	**RT**
Regulation-Up (GWh)	230	229	348	0	0	0	0	0	0	0	0	0
Regulation-Down (GWh)	318	316	266	26	23	2	0	0	0	0	0	0
Flex Up (GWh)	80	86	0	4	5	0	0	0	0	0	0	0
Flex Down (GWh)	95	101	0	17	15	0	0	0	0	0	0	0
Spin (GWh)	1	1	2	1	0	3	0	0	0	0	0	2
Non-Spin (GWh)	87	96	157	18	26	61	0	0	0	9	13	25
Total AS Revenue (k$)	**4,603**	**4,489**	**9,383**	**204**	**216**	**143**	**0**	**0**	**0**	**33**	**41**	**55**

Table 4-7 Swan Lake or LMS100 AS Provision (GWh) and Revenue (k$) by BA with Base RPS and High Gas Price

4.3.3 Swan Lake PSH Operation and Net Revenue in Case of High RPS and Base Gas Price

The following table shows Swan Lake PSH generation, AS provisions and pumping energy in the case of High RPS and base gas price.

The capacity factor of Swan Lake PSH from the RT simulation in this case is 35% ($= \frac{1,187,000}{391.8 \times 8760}$). The net revenue from the RT simulation is 53 million dollars per year (= 65 – 23 + 12). This net revenue yields the Swan Lake PSH value 136 $/kw-year ($= \frac{53,000}{391.8}$).

Swan Lake Operation and Revenue with High RPS and Base Gas Price								
Evaluated Resource	Resource Operation (GWh)				Resource Revenue (mill$/year)			
		DA	HA	RT		DA	HA	RT
	Generation	1,259	1,258	1,187	Pool Revenue	39	39	65
	Pump Load	1,644	1,643	1,547	Pump Cost	(11)	(13)	(23)
	AS Upward Provision	344	348	517	AS Revenue	5	5	12
	AS Downward Provision	513	507	327	Total	32	30	53
Swan Lake					$/kW-Year	83	78	136

Table 4-8 Evaluated Resource Operation and Revenue with High RPS and Base Gas Price

Swan Lake PSH is designated to provide AS to PacifiCorp and CAISO. The following table shows the AS provisions to PacifiCorp and CAISO from Swan Lake PSH. Again, it is noticed that Swan Lake PSH provides majority AS to PacifiCorp and small amount AS to CAISO, most to the downward AS. The reduction of the AS provisions from Swan Lake PSH to CAISO, as opposed to the Phases 1 and 2 study results, is due to the 1.325 GW energy storage facilities modeled in the Phase 3 simulations.

Swan Lake AS Provision (GWh) and Revenue (k$) by BA with High RPS and Base Gas Price						
Evaluated Resource	**Swan Lake**					
BA	**PacifiCorp**			**CAISO**		
AS Product	**DA**	**HA**	**RT**	**DA**	**HA**	**RT**
Regulation-Up (GWh)	210	208	357	0	0	0
Regulation-Down (GWh)	356	358	324	33	31	3
Flex Up (GWh)	55	54	0	4	4	0
Flex Down (GWh)	102	97	0	22	20	0
Spin (GWh)	0	1	2	0	0	2
Non-Spin (GWh)	63	70	109	12	11	47

Total AS Revenue (k$)	**4,515**	**4,527**	**11,415**	**242**	**237**	**117**

Table 4-9 Swan Lake or LMS100 AS Provision (GWh) and Revenue (k$) by BA with High RPS and Base Gas Price

4.4 Generation by Generator Type

This section presents the solutions of generation by generator type from DA, HA and RT simulations. By comparing the generation without and with Swan Lake PSH, one can identify the resources that are displaced by Swan Lake PSH or the LMS100.

4.4.1 Swan Lake PSH's Impact to Generation by Generator Type in Case of Base RPS and Base Gas Price

The following table show the generation from different generator type without and with Swan Lake PSH or LMS100 in the case of base RPS and base gas price. It is can be observed

1. With Swan Lake PSH (under columns of "Swan Lake – Base"), the generations from CCs and CTs are reduced by 241 GWh and 326 GWh from the RT simulation respectively. The hydro and Renewable (RPS) generations are increased by 509 GWh and 245 GWh from the RT simulation respectively. And the generations from other types of resources are increase insignificantly. This indicates that Swan Lake PSH reduces the hydro and renewable generation curtailments by pumping, and displaces the generations from CCs and CTs.
2. With 400 MW of LMS100 (under columns of "LMS100 – Base"), the generations from CCs are reduced, however the generations from CTs are increase.

Generation (GWh) by Generator Type with Base RPS and Base Gas Price															
	Generation (GWh)									Generation Reduction (GWh)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
CC	86,546	91,652	90,930	86,305	91,464	90,689	86,435	91,592	90,845	241	189	241	111	60	85
Coal	24,928	25,021	24,204	24,953	25,047	24,265	24,928	25,027	24,200	(24)	(26)	(61)	1	(6)	4
CT	12,162	12,105	14,628	12,108	12,015	14,302	12,251	12,195	14,693	54	90	326	(89)	(90)	(65)
Hydro	152,322	152,569	146,409	152,759	152,956	146,919	152,342	152,508	146,434	(437)	(387)	(509)	(19)	61	(25)
Nuclear	25,647	25,715	24,780	25,668	25,735	24,800	25,647	25,715	24,779	(22)	(20)	(20)	(1)	0	0
Other	123,511	123,460	119,284	123,508	123,460	119,284	123,513	123,458	119,281	2	(0)	(1)	(2)	2	2
RPS	159,198	154,239	149,296	159,363	154,408	149,541	159,192	154,261	149,307	(165)	(170)	(245)	6	(22)	(11)
Steam	9,186	9,188	8,812	9,185	9,192	8,817	9,186	9,186	8,810	1	(4)	(5)	(0)	2	2
CoGen	7,345	7,420	7,198	7,353	7,429	7,210	7,354	7,427	7,198	(8)	(10)	(12)	(9)	(7)	1
Pumped Storage	5,168	5,165	5,188	6,348	6,306	6,208	5,168	5,160	5,200	(1,180)	(1,142)	(1,020)	(0)	4	(11)
ES Storage	2,335	2,254	2,284	2,340	2,243	2,249	2,343	2,259	2,287	(4)	11	36	(8)	(5)	(3)
Total	608,348	608,787	593,013	609,890	610,256	594,284	608,359	608,787	593,034	(1,542)	(1,469)	(1,271)	(11)	0	(21)

Table 4-10 Generation (GWh) by Generator Type with Base RPS and Base Gas Price

4.4.2 Swan Lake PSH's Impact to Generation by Generator Type in Case of Base RPS and High Gas Price

The following table show the generation from different generator type without and with Swan Lake PSH or LMS100 in the case of base RPS and High gas price. The same can be observed

1. With Swan Lake PSH (under columns of "Swan Lake – Base"), the generations from CCs and CTs are reduced by 332 GWh and 227 GWh from the RT simulation respectively. The hydro and Renewable (RPS) generations are increased by 471 GWh and 226 GWh from the RT simulation respectively. And the generations from other types of resources are increase insignificantly. This indicates that Swan Lake PSH reduces the hydro and renewable generation curtailments by pumping, and displaces the generations from CCs and CTs.

2. With 400 MW of LMS100 (under columns of "LMS100 – Base"), the generations from CCs are reduced, however the generations from CTs are increase slightly. The generations from hydro are increased by 110 GWh.

Generation (GWh) by Generator Type with Base RPS and High Gas Price															
	Generation (GWh)									Generation Reduction (GWh)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
CC	84,788	89,782	89,063	84,594	89,624	88,731	84,692	89,697	88,925	194	157	332	96	85	138
Coal	25,110	25,219	24,381	25,145	25,257	24,449	25,117	25,222	24,374	(35)	(37)	(68)	(8)	(3)	7
CT	11,778	11,687	14,182	11,743	11,631	13,956	11,818	11,752	14,199	34	55	227	(40)	(65)	(17)
Hydro	153,267	153,537	147,523	153,638	153,863	147,994	153,286	153,520	147,633	(371)	(327)	(471)	(19)	16	(110)
Nuclear	25,648	25,717	24,782	25,664	25,739	24,804	25,648	25,719	24,784	(16)	(22)	(23)	(0)	(2)	(2)
Other	124,205	124,168	119,947	124,208	124,165	119,944	124,204	124,169	119,947	(3)	3	3	1	(0)	(0)
RPS	159,608	154,712	149,764	159,745	154,867	150,029	159,634	154,732	149,783	(137)	(156)	(266)	(26)	(20)	(19)
Steam	9,247	9,265	8,886	9,261	9,282	8,904	9,247	9,269	8,890	(14)	(17)	(18)	0	(4)	(4)
CoGen	7,200	7,278	7,008	7,206	7,280	7,015	7,204	7,285	7,001	(6)	(2)	(7)	(4)	(7)	7
Pumped Storage	5,175	5,151	5,166	6,348	6,307	6,181	5,169	5,150	5,163	(1,173)	(1,156)	(1,015)	5	1	4
ES Storage	2,357	2,271	2,305	2,348	2,266	2,270	2,359	2,275	2,316	9	5	35	(1)	(4)	(11)
Total	608,383	608,785	593,006	609,900	610,282	594,276	608,379	608,790	593,014	(1,517)	(1,497)	(1,271)	5	(5)	(8)

Table 4-11 Generation (GWh) by Generator Type with Base RPS and High Gas Price

4.4.3 Swan Lake PSH's Impact to Generation by Generator Type in Case of High RPS and Base Gas Price

The following table show the generation from different generator type without and with Swan Lake PSH in the case of High RPS and base gas price. The following can be observed

1. With Swan Lake PSH (under columns of "Swan Lake – Base"), the generations from CCs and CTs are reduced by 337 GWh and 472 GWh from the RT simulation respectively. The hydro and Renewable (RPS) generations are increased by 622

GWh and 446 GWh from the RT simulation respectively. And the generations from other types of resources are increase insignificantly. This indicates that Swan Lake PSH reduces the hydro and renewable generation curtailments by pumping, and displaces the generations from CCs and CTs.

2. Comparing with the generations in the cases of base RPS and base or high gas price, it is noticeable that the magnitude of the CCs and CTs generation reductions and the hydro and renewable generation increases are bigger in the case of the High RPS and base gas price. This indicates that the PSH demonstrates more benefit in the higher renewable penetration levels.

Generation (GWh) by Generator Type with High RPS and Base Gas Price									
	Generation (GWh)						Generation Reduction (GWh)		
Evaluated Resource	Base			Swan Lake			Swan Lake - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT
CC	76,375	81,957	81,660	76,028	81,600	81,323	347	357	337
Coal	23,929	24,057	23,196	23,950	24,073	23,228	(21)	(16)	(32)
CT	12,743	12,710	15,983	12,692	12,618	15,511	51	92	472
Hydro	150,795	151,056	144,734	151,285	151,606	145,356	(490)	(549)	(622)
Nuclear	25,387	25,439	24,517	25,405	25,468	24,547	(18)	(29)	(30)
Other	114,127	114,060	110,161	114,114	114,061	110,161	14	(2)	(1)
RPS	182,258	176,523	170,295	182,518	176,751	170,741	(260)	(227)	(446)
Steam	8,984	8,995	8,628	8,980	8,996	8,630	3	(1)	(2)
CoGen	6,756	6,862	6,640	6,745	6,848	6,644	11	14	(4)
Pumped Storage	5,675	5,750	5,728	6,887	6,956	6,845	(1,211)	(1,206)	(1,117)
ES Storage	2,501	2,458	2,468	2,494	2,450	2,440	7	8	28
Total	609,529	609,868	594,010	611,097	611,427	595,427	(1,568)	(1,559)	(1,417)

Table 4-12 Generation (GWh) by Generator Type with High RPS and Base Gas Price

4.5 Production Cost by Generator Type

By examining the generation cost, one can identify the types of generators that contribute most to the production cost savings impacted by Swan Lake PSH or LMS100.

4.5.1 Swan Lake PSH's Impact to Production Cost by Generator Type in Case of Base RPS and Base Gas Price

The following table shows the generation cost by generator type in the case of base RPS and base gas price. By comparing the simulations without and with Swan Lake PSH (columns of "Swan Lake – Base"), it can be observed

1. The production cost reduction is from CCs and CTs that is consistent with the generation reduction shown in the previous section. The production cost reduction is 35 million dollars in the RT runs.
2. The production cost reductions from the RT simulation is more than the production cost reductions in the DA or HA simulations. This indicates that Swan Lake PSH demonstrates more benefits in the sub-hourly system energy balancing.

With 400 MW of LMS100, the production cost reduction is from CCs that is much less than the production cost reduction in the case with Swan Lake PSH.

Generation Cost (mill$/year) by Generator Type with Base RPS and Base Gas Price															
Evaluated Resource	Generation Cost (mill$)									Generation Cost Reduction (mill$)					
	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
CC	3,672	3,905	3,851	3,657	3,893	3,837	3,666	3,901	3,846	15	12	14	6	4	5
Coal	405	407	393	406	407	394	405	407	393	(0)	(0)	(1)	(0)	(0)	0
CT	791	783	971	787	777	948	796	788	972	4	6	23	(5)	(5)	(1)
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	361	362	349	361	362	349	361	362	349	(0)	(0)	(0)	(0)	0	0
Other	35	32	30	35	32	30	35	31	30	0	(0)	(0)	(0)	0	0
RPS	319	324	321	319	324	321	319	324	321	(0)	(0)	(0)	(0)	(0)	(0)
Steam	476	476	457	476	476	457	476	476	457	0	(0)	(0)	(0)	0	0
CoGen	235	238	231	235	238	231	235	238	231	(0)	(0)	(0)	(0)	(0)	0
Pumped Storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ES Storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	6,294	6,525	6,604	6,276	6,509	6,568	6,293	6,527	6,600	18	16	35	0	(2)	4

Table 4-13 Generation Cost (mill$) by Generator Type with Base RPS and Base Gas Price

4.5.2 Swan Lake PSH's Impact to Production Cost by Generator Type in Case of Base RPS and High Gas Price

The following table shows the generation cost by generator type in the case of base RPS and High gas price. By comparing the simulations without and with Swan Lake PSH (columns of "Swan Lake – Base"), the same can be observed

1. The production cost reduction is from CCs and CTs that is consistent with the generation reduction shown in the previous section. The production cost reduction is 35 million dollars in the RT runs.
2. The production cost reductions from the RT simulation is more than the production cost reductions in the DA or HA simulations. This indicates that Swan Lake PSH demonstrates more benefits in the sub-hourly system energy balancing.

With 400 MW of LMS100, the production cost reduction is from CCs that is much less than the production cost reduction in the case with Swan Lake PSH.

Generation Cost (mill$/year) by Generator Type with Base RPS and High Gas Price															
	Generation Cost (mill$)									Generation Cost Reduction (mill$)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
CC	4,022	4,277	4,217	4,009	4,262	4,196	4,016	4,271	4,209	13	14	21	6	6	8
Coal	409	410	396	410	411	398	409	410	396	(1)	(1)	(1)	(0)	0	0
CT	852	841	1,042	848	836	1,023	854	845	1,039	4	5	19	(2)	(4)	3
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear	361	362	349	361	362	349	361	362	349	(0)	(0)	(0)	(0)	(0)	(0)
Other	40	38	36	40	37	36	40	38	36	(0)	0	0	0	(0)	(0)
RPS	332	339	335	333	339	336	332	339	335	(1)	(1)	(1)	(0)	(0)	(0)
Steam	521	521	501	522	522	501	521	521	501	(0)	(0)	(1)	0	(0)	(0)
CoGen	254	256	248	254	256	248	254	257	248	(0)	0	(0)	(0)	(0)	0
Pumped Storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ES Storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	6,791	7,043	7,124	6,777	7,026	7,087	6,787	7,042	7,113	15	17	37	4	1	11

Table 4-14 Generation Cost (mill$) by Generator Type with Base RPS and High Gas Price

4.5.3 Swan Lake PSH's Impact to Production Cost by Generator Type in Case of High RPS and Base Gas Price

The following table shows the generation cost by generator type in the case of base RPS and High gas price. By comparing the simulations without and with Swan Lake PSH (columns of "Swan Lake – Base"), the same can be observed

1. The production cost reduction is from CCs and CTs that is consistent with the generation reduction shown in the previous section. The production cost reduction is 35 million dollars in the RT runs.

2. The production cost reductions from the RT simulation is more than the production cost reductions in the DA or HA simulations. This indicates that Swan Lake PSH demonstrates more benefits in the sub-hourly system energy balancing.
3. By comparing with the generation cost reduction in the cases of base RPS and base or high gas price, the production cost reduction in the case of high RPS and base gas price is higher. This indicates that Swan Lake PSH demonstrates more benefit to the higher renewable level by balancing sub-hourly energy.

Generation Cost (mill$/year) by Generator Type with High RPS and Base Gas Price									
	Generation Cost (mill$)						Generation Cost Reduction (mill$)		
Evaluated Resource	Base			Swan Lake			Swan Lake - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT
CC	3,311	3,563	3,522	3,292	3,544	3,504	19	19	18
Coal	391	392	378	390	391	377	1	1	1
CT	829	820	1,075	824	814	1,040	5	6	35
Hydro	-	-	-	-	-	-	-	-	-
Nuclear	357	358	345	358	358	345	(0)	(0)	(0)
Other	38	34	33	38	34	33	1	0	0
RPS	291	298	294	291	298	294	0	(0)	(0)
Steam	472	471	453	471	471	453	0	0	0
CoGen	220	223	217	219	223	217	0	1	(0)
Pumped Storage	-	-	-	-	-	-	-	-	-
ES Storage	-	-	-	-	-	-	-	-	-
Total	5,909	6,161	6,317	5,883	6,134	6,263	26	27	53

Table 4-15 Generation Cost (mill$) by Generator Type with High RPS and Base Gas Price

4.6 Renewable Curtailment

In the pumping mode, Swan Lake PSH can absorb the over-generation from the renewable generators. The previous sections show that Swan Lake PSH helps reduce renewable curtailment across all alternatives. The RT market results show the "true" realized renewable curtailment reduction.

The renewable generation curtailment is calculated by these formulas

$$\begin{aligned}&Renewable\ Curtailment\\&\quad = Defined\ Renewable\ Generation\ Profile\\&\quad - Actual\ Renewable\ Generation\end{aligned}$$

$$\begin{aligned}&Renewable\ Curtailment\ Reduction\ (GWh)\\&\quad = Renewable\ Curtailment_{SL\ (or\ LMS\ case)}\\&\quad - Renewable\ Curtailment_{base\ case}\end{aligned}$$

$$\begin{aligned}&Renewable\ Curtailment\ Reduction\ (\%)\\&\quad = \frac{Renewable\ Curtailment\ Reduction\ (GWh)}{Renewable\ Curtailment(GWh)_{base\ case}}\end{aligned}$$

4.6.1 Swan Lake PSH's Impact to Renewable Generation Curtailment in Case of Base RPS and Base Gas Price

The following chart shows the renewable generation curtailment without and with Swan Lake PSH or LMS100 in the case of base RPS and base gas price. With Swan Lake PSH, the renewable generation curtailment is reduced from the RT simulation by 199 GWh (= 3,090 – 2,891) or 6.4% of the curtailed renewable energy. With 400 MW of LMS100, the renewable generation curtailment is reduced insignificantly by 6 GWh (=3,090 – 3,084) from the RT simulation.

The following table shows the renewable generation curtailment by major BAs in the focused regions. It can be observed (under columns of "Swan Lake – Base") that renewable generation curtailment is reduced most in CAISO by 97 GWh or 4.7% of the curtailed renewable energy.

The 400 MW of LMS100 has little impact to the renewable energy curtailment reduction.

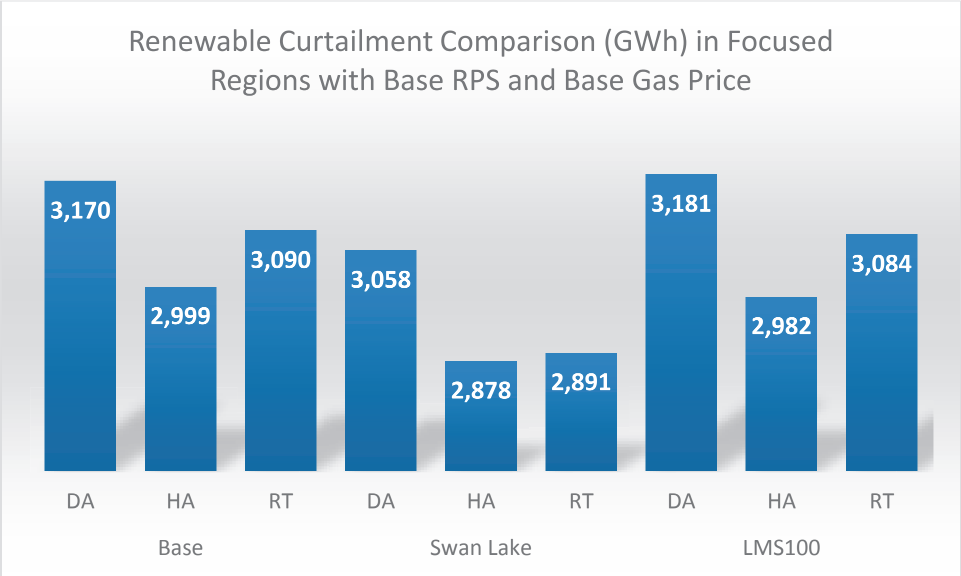

Figure 4-4 Renewable Curtailment Comparison (GWh) in Focused Regions with Base RPS and Base Gas Price

Renewable Curtailment (GWh) and Renewable Curtailment Reduction (GWh) with Base RPS and Base Gas Price															
	Renewable Curtailment (GWh)									Renewable Curtailment Reduction (GWh)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	3,170	2,999	3,090	3,058	2,878	2,891	3,181	2,982	3,084	113	121	199	(11)	16	6
PacifiCorp	36	39	8	31	23	5	37	38	8	6	15	2	(1)	1	(0)
PGE	1	1	1	1	1	1	1	1	1	0	0	0	0	0	(0)
Avista Corp	13	14	5	13	11	3	14	14	5	1	3	1	(1)	0	(0)
Puget Sound	6	6	3	6	5	2	6	6	3	1	1	1	0	(0)	0
PG&E	118	117	113	118	115	112	118	118	113	0	2	1	(0)	(1)	0

SDG&E	18	10	10	16	10	9	19	10	10	1	(0)	2	(1)	(0)	0
SCE	2,133	1,963	2,027	2,070	1,915	1,933	2,130	1,955	2,028	63	48	94	3	8	(1)
LADWP	164	154	95	157	139	82	165	150	94	7	15	12	(1)	4	1
SMUD	1	1	1	1	1	1	1	1	1	(0)	(0)	(0)	(0)	(0)	0
BPA	50	47	16	43	36	12	51	48	16	7	12	4	(1)	(0)	0
CAISO	2,268	2,090	2,151	2,204	2,041	2,053	2,268	2,084	2,150	65	49	97	1	6	0

Table 4-16 Renewable Curtailment (GWh) and Renewable Curtailment Reduction (GWh) with Base RPS and Base Gas Price

4.6.2 Swan Lake PSH's Impact to Renewable Generation Curtailment in Case of Base RPS and High Gas Price

The following chart shows the renewable generation curtailment without and with Swan Lake PSH or LMS100 in the case of base RPS and high gas price. With Swan Lake PSH, the renewable generation curtailment is reduced from the RT simulation by 204 GWh (= 3,093 – 2,889) or 6.6% of the curtailed renewable energy. With 400 MW of LMS100, the renewable generation curtailment is reduced insignificantly by 7 GWh (=3,093 – 3,086) from the RT simulation.

The following table shows the renewable generation curtailment by major BAs in the focused regions. It can be observed (under columns of "Swan Lake – Base") that renewable generation curtailment is reduced most in CAISO by 96 GWh or 4.7% of the curtailed renewable energy.

The 400 MW of LMS100 has little impact to the renewable energy curtailment reduction.

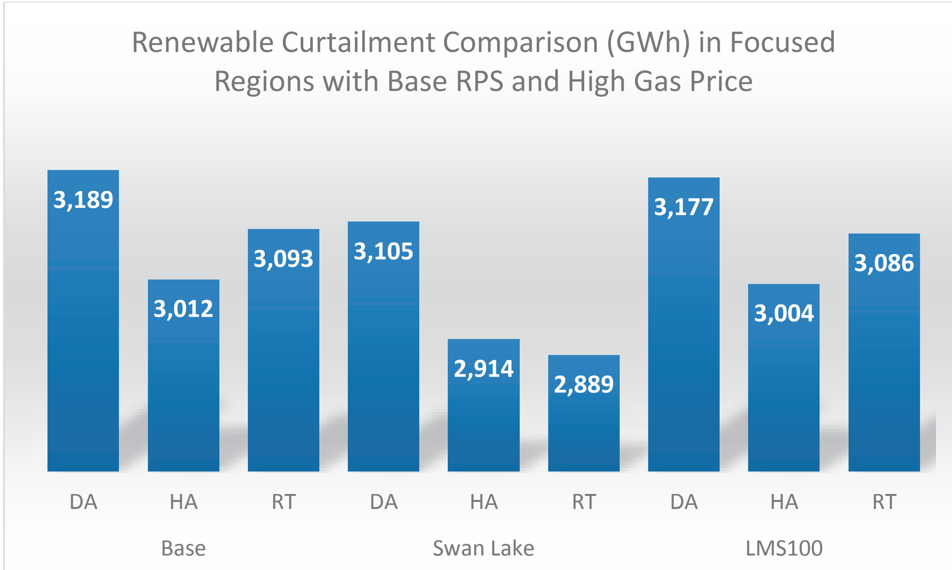

Figure 4-5 Renewable Curtailment Comparison (GWh) in Focused Regions with Base RPS and High Gas Price

Renewable Curtailment (GWh) and Renewable Curtailment Reduction (GWh) with Base RPS and High Gas Price															
	Renewable Curtailment (GWh)									Renewable Curtailment Reduction (GWh)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	3,189	3,012	3,093	3,105	2,914	2,889	3,177	3,004	3,086	84	97	204	12	7	7
PacifiCorp	34	37	8	32	32	6	35	38	8	2	6	2	(1)	(1)	0
PGE	2	2	1	1	1	1	2	2	1	0	0	0	0	(0)	(0)
Avista Corp	13	15	5	12	13	3	12	15	5	1	2	2	1	(0)	0
Puget Sound	7	8	2	6	7	2	7	8	2	1	1	1	(0)	0	0
PG&E	120	120	114	120	119	113	120	122	115	1	1	2	0	(2)	(0)

SDG&E	21	11	11	18	11	9	20	12	10	3	0	2	0	(1)	0
SCE	2,116	1,960	2,024	2,073	1,916	1,931	2,119	1,958	2,018	43	44	93	(3)	2	6
LADWP	175	166	104	168	154	85	172	156	100	7	12	19	3	10	4
SMUD	1	1	1	1	2	1	1	2	1	0	(0)	(0)	(0)	(0)	0
BPA	49	50	17	43	44	13	51	53	17	6	6	4	(2)	(3)	0
CAISO	2,257	2,091	2,149	2,210	2,046	2,053	2,259	2,092	2,143	46	45	96	(3)	(1)	6

Table 4-17 Renewable Curtailment (GWh) and Renewable Curtailment Reduction (GWh) with Base RPS and High Gas Price

4.6.3 Swan Lake PSH's Impact to Renewable Generation Curtailment in Case of High RPS and Base Gas Price

The following chart shows the renewable generation curtailment without and with Swan Lake PSH in the case of High RPS and base gas price. With Swan Lake PSH, the renewable generation curtailment is reduced from the RT simulation by 403 GWh (= 25,408 – 25,005) or 1.6% of the curtailed renewable energy.

The following table shows the renewable generation curtailment by major BAs in the focused regions. It can be observed (under columns of "Swan Lake – Base") that renewable generation curtailment is reduced most in CAISO by 246 GWh or 1.3% of the curtailed renewable energy.

By comparing with the cases of base RPS and base or high gas price, the renewable generation curtailment reduction in the case of high RPS and base gas price is more. This indicates that Swan Lake PSH demonstrates the benefit more to the higher renewable penetration levels.

The 400 MW of LMS100 has little impact to the renewable energy curtailment reduction.

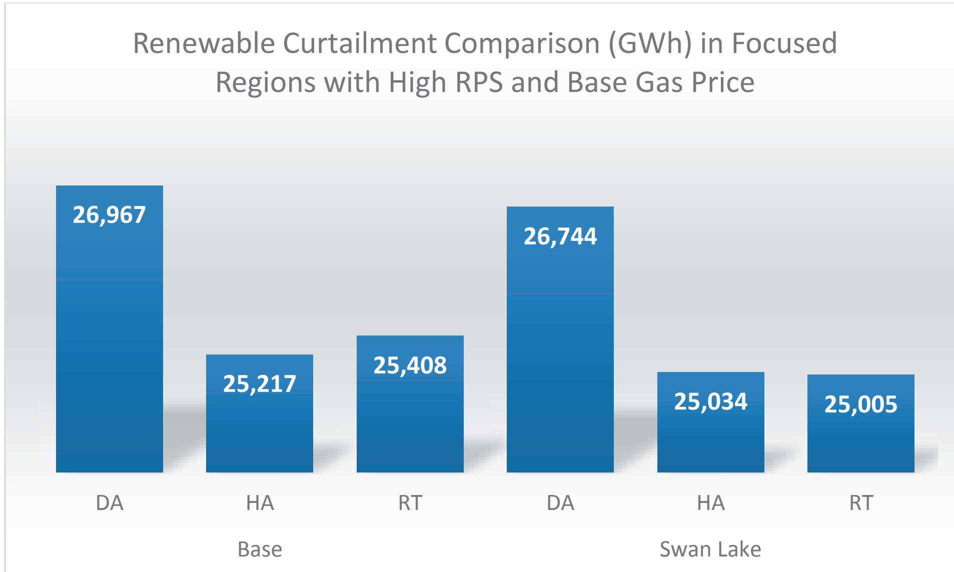

Figure 4-6 Renewable Curtailment Comparison (GWh) in Focused Regions with High RPS and Base Gas Price

Renewable Curtailment (GWh) and Renewable Curtailment Reduction (GWh) with High RPS and Base Gas Price									
	Renewable Curtailment (GWh)						Renewable Curtailment Reduction (GWh)		
Evaluated Resource	Base			Swan Lake			Swan Lake - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	26,967	25,217	25,408	26,744	25,034	25,005	223	184	403
PacifiCorp	229	267	228	221	266	224	8	1	3
PGE	3	3	3	3	3	2	0	0	1
Avista Corp	11	16	7	10	15	6	1	1	1
Puget Sound	8	8	4	7	7	3	1	1	1

PG&E	817	607	614	822	608	611	(4)	(1)	2
SDG&E	257	169	186	272	164	184	(16)	5	2
SCE	19,311	18,508	18,688	19,116	18,394	18,445	195	114	242
LADWP	1,088	893	717	997	862	634	91	31	83
SMUD	2,288	1,876	1,828	2,286	1,878	1,828	2	(1)	0
BPA	46	55	23	38	52	18	8	3	5
CAISO	20,385	19,284	19,488	20,210	19,166	19,241	175	119	246

Table 4-18 Renewable Curtailment (GWh) and Renewable Curtailment Reduction (GWh) with High RPS and Base Gas Price

4.7 Emission Production

Swan Lake PSH may change the thermal generator operations thus change the emission production in the focused regions. This section presents the Swan Lake PSH's impact to the emission production in different cases.

4.7.1 Swan Lake PSH's Impact to Emission Production in Case of base RPS and Base Gas Price

The following chart shows the comparison of the emission production in the focused regions without and with Swan Lake PSH or LMS100. With Swan Lake PSH, the emission production is reduced by 200,000 tons (= 87.47 – 87.27) from the RT simulation. And with LMS100, the emission production is reduced by 30,000 tons (=87.47 – 87.44) from the RT simulation.

The following table shows the comparison of the emission production for major BAs in the focused regions.

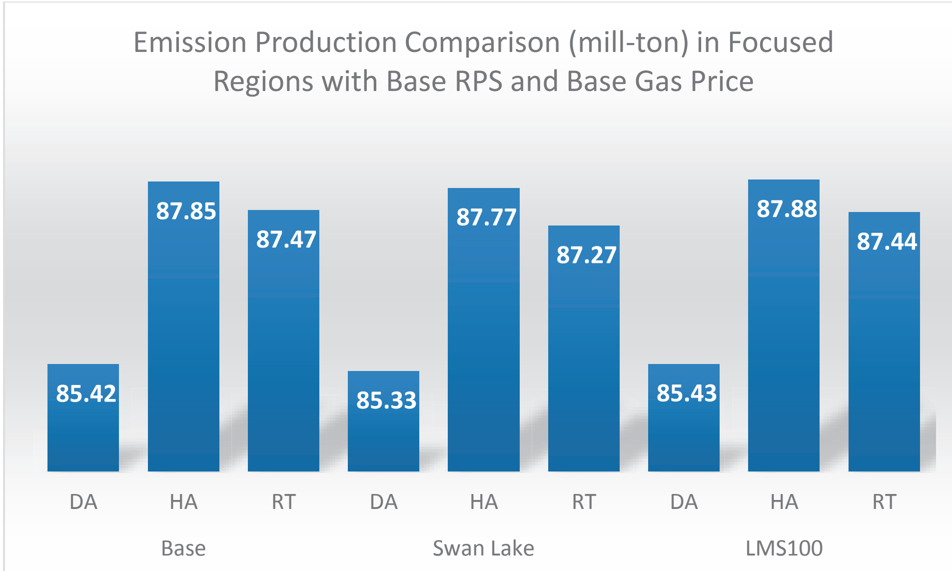

Figure 4-7 Emission Production Comparison (mill-ton) in Focused Regions with Base RPS and Base Gas Price

Emission Production (mill-ton) and Emission Production Reduction (mill-ton) with Base RPS and Base Gas Price															
	Emission Production (mill-ton)									Emission Production Reduction (mill-ton)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	85.42	87.85	87.47	85.33	87.77	87.27	85.43	87.88	87.44	0.09	0.08	0.21	(0.01)	(0.03)	0.03
PacifiCorp	2.98	3.00	3.00	2.97	2.99	2.99	2.98	3.00	3.00	0.01	0.01	0.01	0.00	(0.00)	0.00
PGE	0.79	0.84	0.83	0.79	0.83	0.82	0.79	0.84	0.83	0.00	0.01	0.01	0.00	(0.00)	(0.00)
Avista Corp	0.63	0.69	0.64	0.63	0.69	0.64	0.63	0.68	0.64	0.00	(0.00)	(0.00)	(0.00)	0.01	0.01
Puget Sound	1.56	1.55	1.57	1.56	1.55	1.57	1.56	1.55	1.57	0.00	0.00	0.01	(0.00)	(0.00)	0.00
PG&E	15.65	16.33	16.57	15.64	16.33	16.51	15.65	16.35	16.54	0.01	0.00	0.06	0.00	(0.02)	0.04

SDG&E	6.82	7.07	6.98	6.81	7.05	6.95	6.82	7.06	6.97	0.01	0.02	0.03	(0.00)	0.01	0.01
SCE	21.01	21.22	21.24	20.96	21.16	21.14	21.00	21.21	21.18	0.05	0.06	0.10	0.01	0.01	0.05
LADWP	13.92	14.15	13.78	13.92	14.18	13.81	13.92	14.16	13.77	(0.00)	(0.02)	(0.03)	(0.00)	(0.01)	0.02
SMUD	2.51	2.47	2.61	2.52	2.47	2.60	2.52	2.47	2.61	(0.00)	(0.00)	0.01	(0.00)	(0.00)	0.00
BPA	6.96	7.17	6.94	6.92	7.15	6.94	6.97	7.20	7.07	0.04	0.01	(0.00)	(0.02)	(0.03)	(0.14)
CAISO	43.48	44.62	44.80	43.42	44.54	44.60	43.47	44.62	44.69	0.07	0.08	0.19	0.01	0.00	0.10

Table 4-19 Emission Production (mill-ton) and Emission Production Reduction (mill-ton) with Base RPS and Base Gas Price

4.7.2 Swan Lake PSH's Impact to Emission Production in Case of Base RPS and High Gas Price

The following chart shows the comparison of the emission production in the focused regions without and with Swan Lake PSH or LMS100. With Swan Lake PSH, the emission production is reduced by 170,000 tons (= 87.09 – 86.92) from the RT simulation. And with LMS100, the emission production is reduced by 80,000 tons (= 87.09 – 87.01) from the RT simulation.

The following table shows the comparison of the emission production for major BAs in the focused regions.

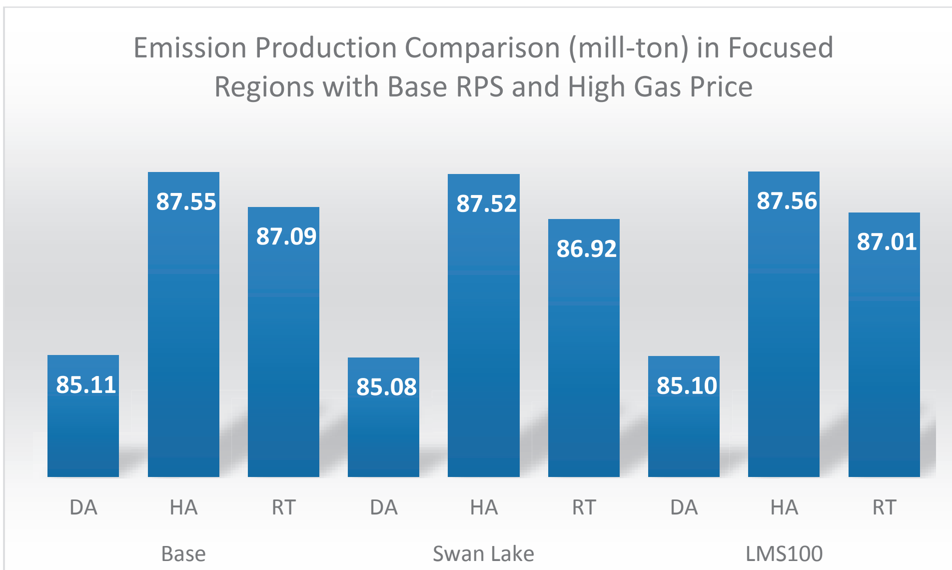

Figure 4-8 Emission Production Comparison (mill-ton) in Focused Regions with Base RPS and High Gas Price

Emission Production (mill-ton) and Emission Production Reduction (mill-ton) with Base RPS and High Gas Price															
	Emission Production (mill-ton)									Emission Production Reduction (mill-ton)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	85.11	87.55	87.09	85.08	87.52	86.92	85.10	87.56	87.01	0.03	0.03	0.17	0.01	(0.01)	0.07
PacifiCorp	2.95	2.97	2.97	2.96	2.98	2.97	2.95	2.98	2.97	(0.00)	(0.00)	0.01	0.00	(0.00)	0.00
PGE	0.80	0.85	0.84	0.80	0.85	0.84	0.80	0.84	0.83	(0.00)	0.00	0.00	(0.00)	0.00	0.01
Avista Corp	0.66	0.73	0.68	0.66	0.73	0.68	0.66	0.72	0.67	(0.00)	(0.00)	(0.01)	0.00	0.01	0.01
Puget Sound	1.51	1.51	1.53	1.51	1.52	1.53	1.51	1.52	1.53	(0.00)	(0.00)	0.00	(0.00)	(0.00)	0.00
PG&E	15.63	16.30	16.52	15.62	16.28	16.43	15.62	16.30	16.46	0.01	0.03	0.09	0.01	(0.00)	0.06
SDG&E	6.76	6.99	6.89	6.74	6.98	6.88	6.75	6.98	6.87	0.01	0.00	0.01	0.01	0.01	0.02
SCE	20.85	21.04	21.06	20.81	21.01	20.99	20.83	21.03	21.00	0.04	0.03	0.07	0.01	0.01	0.06
LADWP	13.91	14.13	13.75	13.93	14.14	13.76	13.92	14.13	13.73	(0.02)	(0.01)	(0.02)	(0.00)	0.00	0.02
SMUD	2.41	2.43	2.58	2.41	2.43	2.57	2.41	2.44	2.57	(0.00)	0.00	0.01	0.00	(0.01)	0.00
BPA	7.03	7.25	7.02	7.04	7.28	7.05	7.05	7.29	7.15	(0.02)	(0.03)	(0.03)	(0.03)	(0.04)	(0.13)
CAISO	43.23	44.33	44.47	43.18	44.27	44.30	43.20	44.31	44.33	0.06	0.06	0.17	0.03	0.02	0.14

Table 4-20 Emission Production (mill-ton) and Emission Production Reduction (mill-ton) with Base RPS and High Gas Price

4.7.3 Swan Lake PSH's Impact to Emission Production in Case of High RPS and Base Gas Price

The following chart shows the comparison of the emission production in the focused regions without and with Swan Lake PSH. With Swan Lake PSH, the emission production is reduced by 390,000 tons (= 82.37 – 81.98) from the RT simulation.

The following table shows the comparison of the emission production for major BAs in the focused regions.

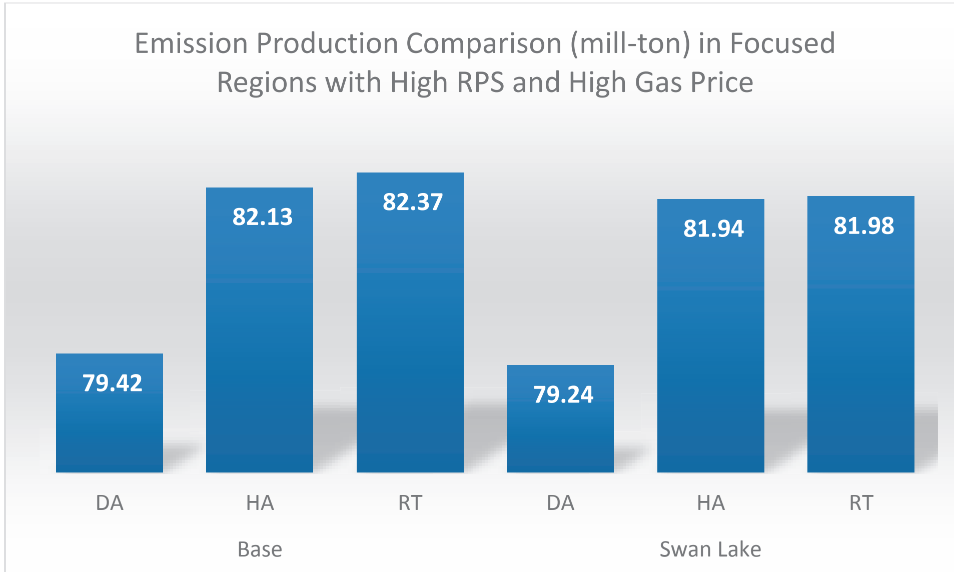

Figure 4-9 Emission Production Comparison (mill-ton) in Focused Regions with High RPS and High Gas Price

Emission Production (mill-ton) and Emission Production Reduction (mill-ton) with High RPS and Base Gas Price									
	Emission Production (mill-ton)						Emission Production Reduction (mill-ton)		
Evaluated Resource	**Base**			**Swan Lake**			**Swan Lake - Base**		
	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	79.42	82.13	82.37	79.24	81.94	81.98	0.19	0.19	0.39
PacifiCorp	2.86	2.89	2.92	2.85	2.88	2.91	0.01	0.01	0.01
PGE	0.75	0.79	0.78	0.75	0.78	0.77	(0.00)	0.01	0.01
Avista Corp	0.54	0.59	0.57	0.54	0.59	0.56	(0.00)	0.00	0.01
Puget Sound	1.50	1.52	1.54	1.50	1.51	1.54	0.00	0.01	0.01

PG&E	13.80	14.62	15.10	13.75	14.56	14.96	0.04	0.06	0.14
SDG&E	6.38	6.65	6.57	6.37	6.64	6.55	0.01	0.01	0.02
SCE	19.68	19.90	20.05	19.61	19.85	19.96	0.07	0.05	0.09
LADWP	13.13	13.39	13.10	13.25	13.50	13.19	(0.12)	(0.11)	(0.09)
SMUD	2.27	2.31	2.47	2.26	2.31	2.47	0.01	0.00	0.00
BPA	6.47	6.67	6.48	6.33	6.54	6.35	0.14	0.12	0.13
CAISO	39.86	41.17	41.72	39.74	41.05	41.47	0.12	0.13	0.25

Table 4-21 Emission Production (mill-ton) and Emission Production Reduction (mill-ton) with High RPS and Base Gas Price

4.8 Thermal Generator Cycling

This section analyzes the Swan Lake PSH's impact to the thermal generation cycling, i.e., number of start, startup costs, ramp up mileages and ramp down mileages.

4.8.1 Swan Lake PSH's Impact to Thermal Generator Number of Starts

This sub-section presents the Swan Lake PSH's impact to the thermal generator number of starts in different cases.

4.8.1.1 Swan Lake PSH's Impact to Thermal Number of Starts in Case of Base RPS and Base Gas Price

The following chart shows the thermal generators number of starts without and with Swan Lake PSH or LMS100 in the case of base RPS and base gas price. With Swan Lake PSH, the thermal generator number of starts in the focused regions is reduced by 2,469 (=51,888 – 49,419) or 4.8% from the RT simulation. With 400 MW of LMS100, the thermal generator number of starts is reduced by 1,425 (=51,888 – 50,463) or 2.7% from the RT simulation.

The following table shows the thermal generators number of starts without and with Swan Lake PSH or LMS100 for the major BAs in the focused regions. With Swan Lake PSH, the thermal generator number of starts is reduced by 1,711 or 4.5% of total number of starts in CAISO from the RT simulation, i.e., CAISO is the major beneficiary of Swan Lak PSH. With 400 MW of LMS100, the thermal generator number of start is reduced by 2,057 in CAISO from the RT simulation, i.e., CAISO is the major beneficiary of LMS100.

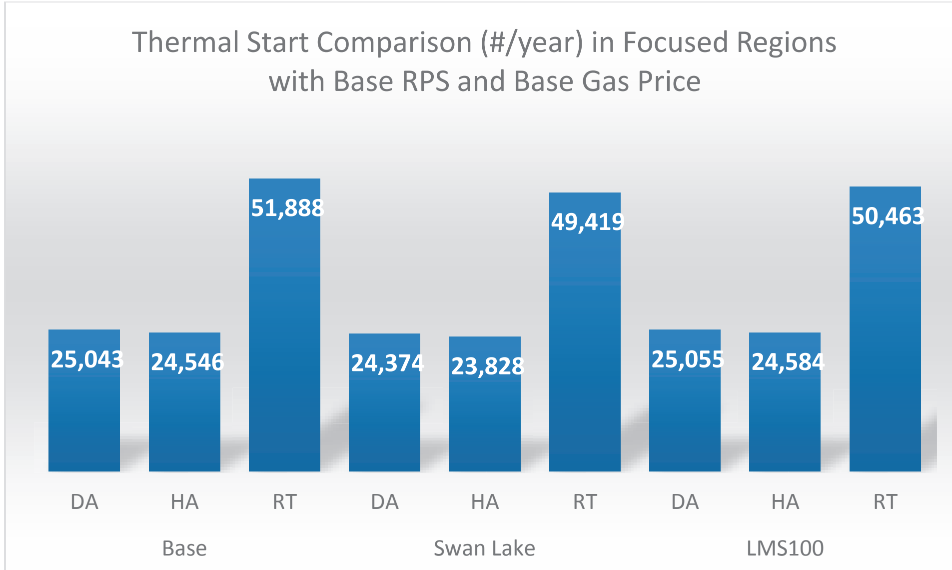

Figure 4-10 Thermal Start Comparison (#/year) in Focused Regions with Base RPS and Base Gas Price

Thermal Number of Starts (#/year) and Thermal Number of Start Reduction (#/year) with Base RPS and Base Gas Price															
	Thermal number of Starts (#/year)									Thermal number of Start Reduction (#/year)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	25,043	24,546	51,888	24,374	23,828	49,419	25,055	24,584	50,463	669	718	2,469	(12)	(38)	1,425
PacifiCorp	122	139	365	116	134	310	111	130	306	6	5	55	11	9	59
PGE	43	67	64	43	62	59	42	66	63	-	5	5	1	1	1
Avista Corp	607	607	668	587	574	616	607	601	639	20	33	52	-	6	29
Puget Sound	101	105	294	98	101	239	97	99	251	3	4	55	4	6	43
PG&E	4,531	4,464	12,265	4,397	4,273	11,205	4,474	4,403	11,025	134	191	1,060	57	61	1,240

SDG&E	2,377	2,418	3,657	2,348	2,425	3,524	2,368	2,409	3,471	29	(7)	133	9	9	186
SCE	12,282	11,652	23,980	11,953	11,321	23,462	12,074	11,528	23,349	329	331	518	208	124	631
LADWP	792	765	2,173	778	732	1,967	794	736	1,945	14	33	206	(2)	29	228
SMUD	595	484	1,186	586	487	1,061	589	483	1,063	9	(3)	125	6	1	123
BPA	512	623	929	473	598	822	880	921	2,480	39	25	107	(368)	(298)	(1,551)
CAISO	19,190	18,534	39,902	18,698	18,019	38,191	18,916	18,340	37,845	492	515	1,711	274	194	2,057

Table 4-22 Thermal Number of Starts (#/year) and Thermal Number of Start Reduction (#/year) with Base RPS and Base Gas Price

4.8.1.2 Swan Lake PSH's Impact to Thermal Number of Starts in Case of Base RPS and High Gas Price

The following chart shows the thermal generators number of starts without and with Swan Lake PSH or LMS100 in the case of base RPS and High gas price. With Swan Lake PSH, the thermal generator number of starts in the focused regions is reduced by 1,806 (=50,612 – 48,806) or 3.6% from the RT simulation. With 400 MW of LMS100, the thermal generator number of starts is reduced by 1,881 (=50,612 – 48,731) or 3.7% from the RT simulation.

The following table shows the thermal generators number of starts without and with Swan Lake PSH or LMS100 for the major BAs in the focused regions. With Swan Lake PSH, the thermal generator number of starts is reduced by 1,297 or 3.4% of total number of starts in CAISO from the RT simulation, i.e., CAISO is the major beneficiary of Swan Lake PSH. With 400 MW of LMS100, the thermal generator number of start is reduced by 2,436 in CAISO from the RT simulation, i.e., CAISO is the major beneficiary of LMS100.

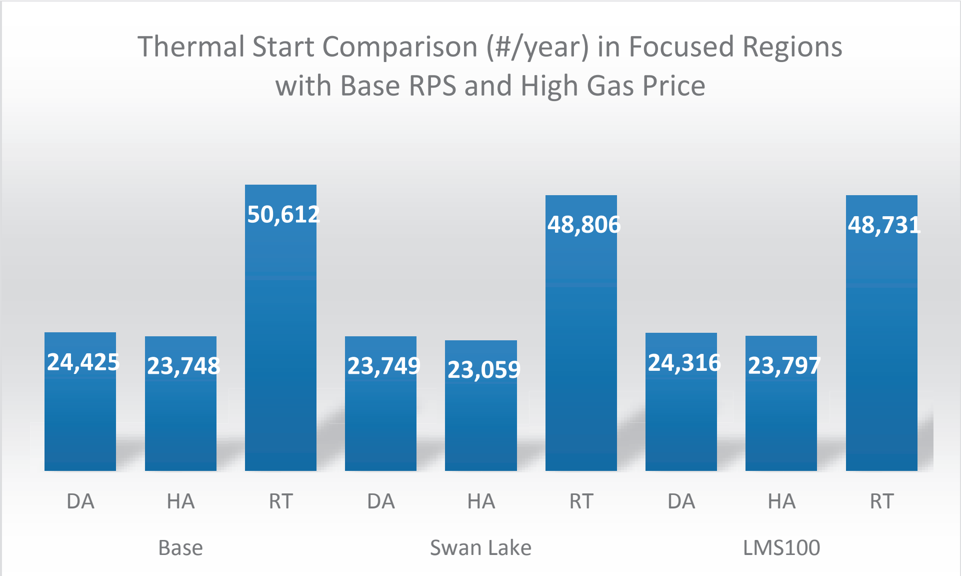

Figure 4-11 Thermal Start Comparison (#/year) in Focused Regions with Base RPS and High Gas Price

Thermal Number of Starts (#/year) and Thermal Number of Start Reduction (#/year) with Base RPS and High Gas Price															
	Thermal Number of Starts (#/year)									Thermal Number of Start Reduction (#/year)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	24,425	23,748	50,612	23,749	23,059	48,806	24,316	23,797	48,731	676	689	1,806	109	(49)	1,881
PacifiCorp	115	121	343	113	125	303	110	121	289	2	(4)	40	5	-	54
PGE	45	66	63	45	62	59	45	62	59	-	4	4	-	4	4
Avista Corp	613	587	632	586	564	609	608	584	615	27	23	23	5	3	17

Puget Sound	96	102	265	95	96	238	90	97	223	1	6	27	6	5	42
PG&E	4,414	4,338	11,775	4,267	4,182	10,820	4,315	4,274	10,570	147	156	955	99	64	1,205
SDG&E	2,367	2,475	3,638	2,351	2,438	3,559	2,336	2,465	3,502	16	37	79	31	10	136
SCE	12,080	11,235	23,595	11,657	10,879	23,332	11,797	11,109	22,500	423	356	263	283	126	1,095
LADWP	725	653	2,106	725	637	1,925	702	637	1,938	-	16	181	23	16	168
SMUD	599	504	1,148	594	495	1,022	593	500	1,027	5	9	126	6	4	121
BPA	509	607	889	483	579	810	879	928	2,380	26	28	79	(370)	(321)	(1,491)
CAISO	18,861	18,048	39,008	18,275	17,499	37,711	18,448	17,848	36,572	586	549	1,297	413	200	2,436

Table 4-23 Thermal Number of Starts (#/year) and Thermal Number of Start Reduction (#/year) with Base RPS and High Gas Price

4.8.1.3 Swan Lake PSH's Impact to Thermal Number of Starts in Case of High RPS and Base Gas Price

The following chart shows the thermal generators number of starts without and with Swan Lake PSH in the case of High RPS and base gas price. With Swan Lake PSH, the thermal generator number of starts in the focused regions is reduced by 3,111 (=60,962 – 57,851) or 5.1% from the RT simulation.

The following table shows the thermal generators number of starts without and with Swan Lake PSH for the major BAs in the focused regions. With Swan Lake PSH, the thermal generator number of starts is reduced by 1,867 or 4.3% of total number of starts in CAISO from the RT simulation, i.e., CAISO is the major beneficiary of Swan Lake PSH.

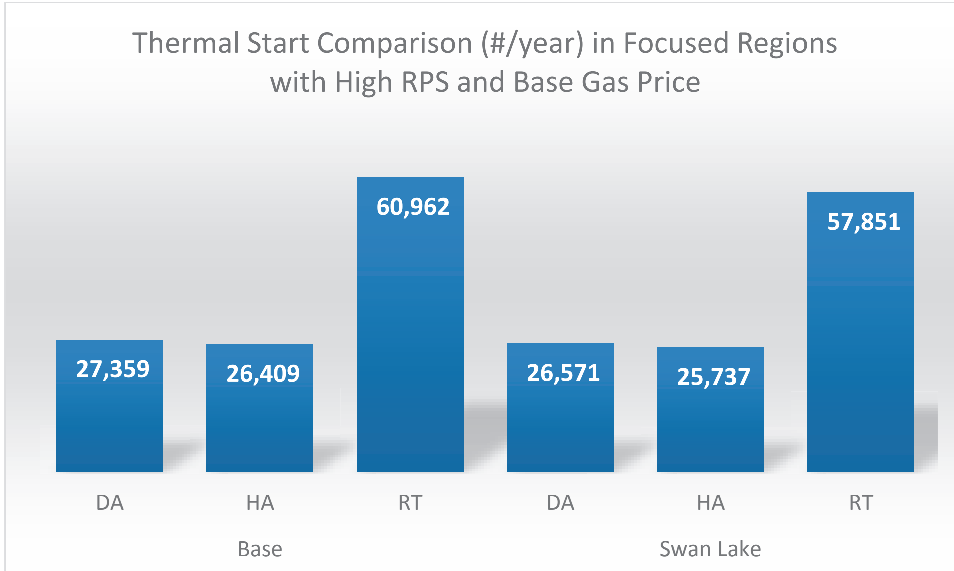

Figure 4-12 Thermal Start Comparison (#/year) in Focused Regions with High RPS and Base Gas Price

Thermal Number of Starts (#/year) and Thermal Number of Start Reduction (#/year) with High RPS and Base Gas Price									
	Thermal Number of Starts (#/year)						Thermal Number of Start Reduction (#/year)		
Evaluated Resource	Base			Swan Lake			Swan Lake - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	27,359	26,409	60,962	26,571	25,737	57,851	788	672	3,111
PacifiCorp	140	140	534	136	141	464	4	(1)	70
PGE	39	52	48	40	51	47	(1)	1	1
Avista Corp	561	589	780	546	569	700	15	20	80

Puget Sound	94	98	453	90	99	389	4	(1)	64
PG&E	4,970	4,602	14,661	4,761	4,459	13,660	209	143	1,001
SDG&E	2,845	2,931	3,948	2,847	2,936	3,859	(2)	(5)	89
SCE	13,245	12,595	26,497	12,901	12,257	25,720	344	338	777
LADWP	1,103	952	3,161	1,051	903	2,860	52	49	301
SMUD	639	534	1,503	625	528	1,370	14	6	133
BPA	482	561	1,234	449	546	1,080	33	15	154
CAISO	21,060	20,128	45,106	20,509	19,652	43,239	551	476	1,867

Table 4-24 Thermal Number of Starts (#/year) and Thermal Number of Start Reduction (#/year) with High RPS and Base Gas Price

4.8.2 Swan Lake PSH's Impact to Thermal Generator Starts Cost

This sub-section presents the Swan Lake PSH's impact to the thermal generator start cost in different cases.

4.8.2.1 Swan Lake PSH's Impact to Thermal Start Cost in Case of Base RPS and Base Gas Price

The following chart shows the thermal generator start cost without and with Swan Lake PSH or LMS100 in the case of base RPS and base gas price. With Swan Lake PSH, the thermal generator start cost in the focused regions is reduced by 10.66 million dollars per year (=352.56 – 341.90) or 3.0% of total start cost from the RT simulation. With 400 MW of LMS100, the thermal generator start cost is reduced by 3.14 million dollars per year (=352.56 – 349.42) or 0.9% of total start cost from the RT simulation.

The following table shows the thermal generators start cost without and with Swan Lake PSH or LMS100 for the major BAs in the focused regions. With Swan Lake PSH, the thermal generator start cost is reduced by 7.37million dollars per year or 3.6% of total start cost in CAISO from the RT simulation (under columns of "Swan Lake – Base"), i.e., CAISO is the major beneficiary of Swan Lake PSH.

With 400 MW of LMS100, the thermal generator start cost is reduced by 5.18 million dollars per year in CAISO from the RT simulation (under columns of "LMS100 – Base"). However, in some major BAs, the generator start cost is increased. Therefore the bi-directional thermal generator start cost change by BA may not reflect the true BA thermal generator start cost savings by LMS100.

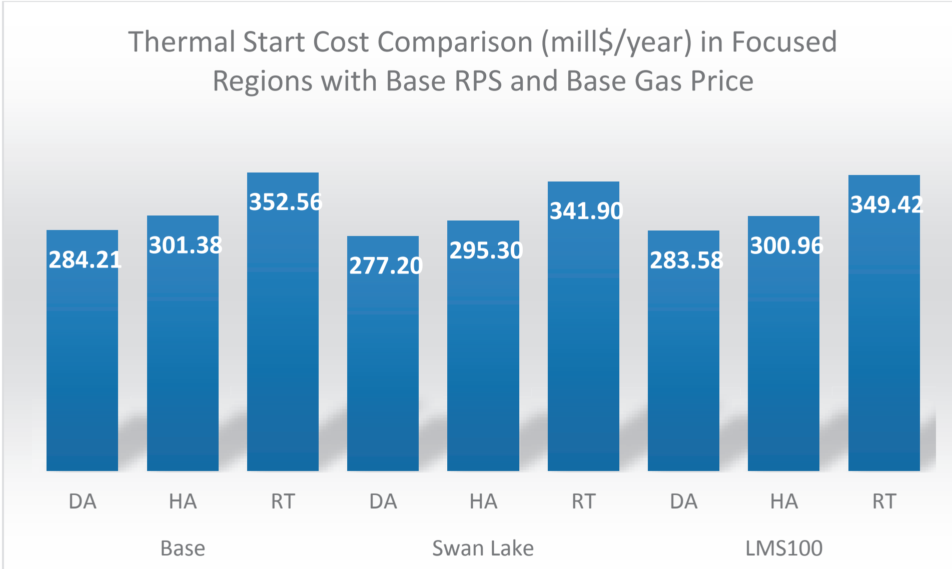

Figure 4-13 Thermal Start Cost Comparison (#/year) in Focused Regions with Base RPS and Base Gas Price

Thermal Start Cost (mill$/year) and Thermal Start Cost Reduction (mill$/year) with Base RPS and Base Gas Price															
	Thermal Start Cost (mill$/year)									Thermal Start Cost Reduction (mill$/year)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	284.21	301.38	352.56	277.20	295.30	341.90	283.58	300.96	349.42	7.02	6.07	10.66	0.63	0.42	3.14
PacifiCorp	2.18	2.21	2.64	2.17	2.20	2.52	2.15	2.20	2.51	0.01	0.01	0.12	0.02	0.02	0.13
PGE	1.02	1.95	1.85	1.02	1.76	1.65	0.98	1.91	1.81	0.00	0.19	0.19	0.04	0.04	0.04
Avista Corp	2.73	3.33	3.62	2.71	3.26	3.43	2.75	3.20	3.35	0.03	0.07	0.18	(0.02)	0.14	0.27
Puget Sound	1.54	1.55	1.94	1.53	1.54	1.82	1.53	1.54	1.84	0.01	0.01	0.12	0.01	0.01	0.10

PG&E	63.67	65.37	80.43	61.38	63.08	76.06	63.41	64.84	77.37	2.29	2.29	4.37	0.26	0.53	3.05
SDG&E	17.87	19.14	21.17	17.69	18.86	20.54	17.82	18.98	20.63	0.17	0.28	0.63	0.05	0.16	0.54
SCE	89.78	87.66	108.51	87.56	86.07	106.13	88.68	87.65	106.93	2.23	1.59	2.37	1.10	0.02	1.58
LADWP	14.84	16.47	21.71	14.10	16.04	20.56	14.90	16.41	20.50	0.74	0.43	1.14	(0.06)	0.06	1.20
SMUD	14.08	11.23	12.57	13.88	11.36	12.41	14.14	11.22	12.22	0.20	(0.13)	0.16	(0.06)	0.01	0.35
BPA	10.98	14.10	13.81	10.01	13.52	13.13	12.17	15.04	19.46	0.97	0.58	0.68	(1.20)	(0.94)	(5.65)
CAISO	171.32	172.18	210.11	166.63	168.01	202.73	169.91	171.47	204.93	4.69	4.16	7.37	1.41	0.71	5.18

Table 4-25 Thermal Start Cost (mill$/year) and Thermal Start Cost Reduction (mill$/year) with Base RPS and Base Gas Price

4.8.2.2 Swan Lake PSH's Impact to Thermal Start Cost in Case of Base RPS and High Gas Price

The following chart shows the thermal generator start cost without and with Swan Lake PSH or LMS100 in the case of base RPS and High gas price. With Swan Lake PSH, the thermal generator start cost in the focused regions is reduced by 11.04 million dollars per year (=364.66 – 353.62) or 3.0% of total start cost from the RT simulation. With 400 MW of LMS100, the thermal generator start cost is reduced by 4.66 million dollars per year (=364.66 – 360.00) or 1.3% of total start cost from the RT simulation.

The following table shows the thermal generators start cost without and with Swan Lake PSH or LMS100 for the major BAs in the focused regions. With Swan Lake PSH, the thermal generator start cost is reduced by 8.53 million dollars per year or 4.0% of total start cost in CAISO from the RT simulation (under columns of "Swan Lake – Base"), i.e., CAISO is the major beneficiary of Swan Lake PSH.

With 400 MW of LMS100, the thermal generator start cost is reduced by 6.82 million dollars per year in CAISO from the RT simulation (under columns of "LMS100 – Base"). However, in some major BAs, the generator start cost is increased. Therefore the bi-directional thermal generator start cost change by BA may not reflect the true BA thermal generator start cost savings by LMS100.

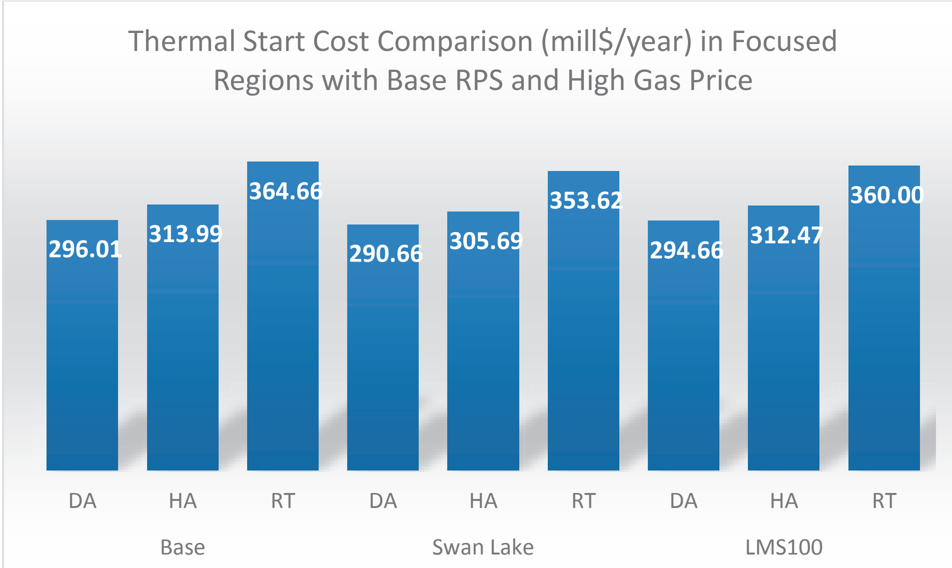

Figure 4-14 Thermal Start Cost Comparison (#/year) in Focused Regions with Base RPS and High Gas Price

Thermal Start Cost (mill$/year) and Thermal Start Cost Reduction (mill$/year) with Base RPS and High Gas Price															
	Thermal Start Cost (mill$/year)									Thermal Start Cost Reduction (mill$/year)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	296.01	313.99	364.66	290.66	305.69	353.62	294.66	312.47	360.00	5.36	8.30	11.04	1.35	1.52	4.66
PacifiCorp	2.21	2.22	2.64	2.20	2.23	2.55	2.20	2.22	2.52	0.00	(0.01)	0.09	0.01	-	0.12
PGE	1.12	1.95	1.85	1.12	1.79	1.69	1.12	1.79	1.68	0.00	0.16	0.16	(0.00)	0.17	0.17
Avista Corp	2.81	3.48	3.61	2.72	3.41	3.61	2.75	3.33	3.44	0.09	0.07	(0.00)	0.06	0.15	0.16
Puget Sound	1.57	1.58	1.92	1.56	1.57	1.86	1.55	1.57	1.83	0.00	0.01	0.06	0.01	0.01	0.10
PG&E	68.47	71.41	85.85	65.99	67.68	80.68	67.72	69.88	81.80	2.48	3.73	5.16	0.75	1.52	4.05

SDG&E	19.01	20.09	21.96	18.70	19.82	21.64	18.76	20.21	21.82	0.31	0.26	0.32	0.25	(0.12)	0.14
SCE	93.15	90.22	111.40	91.55	87.56	108.35	91.93	89.72	108.77	1.60	2.66	3.05	1.22	0.49	2.63
LADWP	15.89	16.70	22.04	15.81	16.39	21.21	15.88	16.70	21.13	0.07	0.31	0.83	0.01	0.00	0.91
SMUD	14.71	11.88	13.06	14.80	11.82	12.73	14.75	11.79	12.67	(0.10)	0.06	0.34	(0.05)	0.09	0.39
BPA	11.42	14.27	13.82	10.92	13.65	13.26	12.70	15.60	19.67	0.50	0.62	0.55	(1.28)	(1.33)	(5.86)
CAISO	180.63	181.71	219.21	176.24	175.06	210.68	178.41	179.82	212.39	4.39	6.65	8.53	2.22	1.89	6.82

Table 4-26 Thermal Start Cost (mill$/year) and Thermal Start Cost Reduction (mill$/year) with Base RPS and High Gas Price

4.8.2.3 Swan Lake PSH's Impact to Thermal Start Cost in Case of High RPS and Base Gas Price

The following chart shows the thermal generator start cost without and with Swan Lake PSH in the case of High RPS and base gas price. With Swan Lake PSH, the thermal generator start cost in the focused regions is reduced by 14.09 million dollars per year (=387.61 – 373.52) or 3.6% of total start cost from the RT simulation.

The following table shows the thermal generators start cost without and with Swan Lake PSH for the major BAs in the focused regions. With Swan Lake PSH, the thermal generator start cost is reduced by 8.01 million dollars per year or 3.6% of total start cost in CAISO from the RT simulation (under columns of "Swan Lake – Base"), i.e., CAISO is the major beneficiary of Swan Lake PSH.

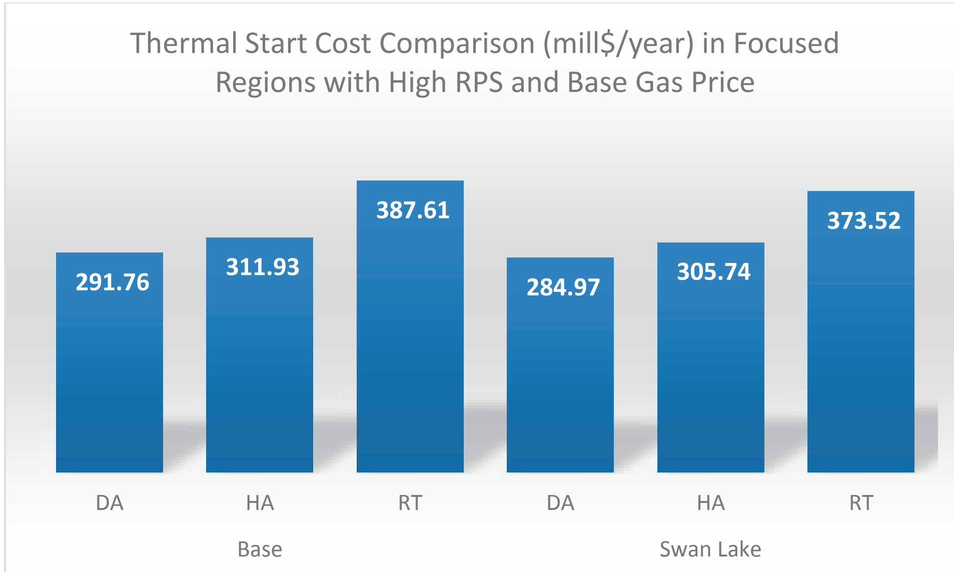

Figure 4-15 Thermal Start Cost Comparison (#/year) in Focused Regions with High RPS and Base Gas Price

Thermal Start Cost (mill$/year) and Thermal Start Cost Reduction (mill$/year) with High RPS and Base Gas Price									
	Thermal Start Cost (mill$/year)						Thermal Start Cost Reduction (mill$/year)		
Evaluated Resource	Base			Swan Lake			Swan Lake - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	291.76	311.93	387.61	284.97	305.74	373.52	6.79	6.19	14.09
PacifiCorp	2.22	2.22	3.00	2.21	2.22	2.85	0.01	(0.00)	0.15
PGE	0.89	1.39	1.23	0.92	1.35	1.19	(0.04)	0.04	0.04
Avista Corp	2.10	2.71	3.70	2.10	2.66	3.35	(0.00)	0.05	0.35
Puget Sound	1.52	1.53	2.29	1.52	1.54	2.15	0.01	(0.00)	0.14

PG&E	60.29	64.08	86.22	58.58	62.27	81.30	1.72	1.81	4.91
SDG&E	19.77	21.61	22.68	19.67	21.47	22.42	0.09	0.14	0.26
SCE	97.91	95.07	119.11	94.99	93.12	116.27	2.92	1.95	2.84
LADWP	17.55	18.93	31.02	16.81	17.93	28.49	0.74	1.00	2.52
SMUD	15.25	12.71	14.86	15.17	12.63	14.26	0.09	0.08	0.60
BPA	8.85	11.56	11.67	8.33	11.48	11.44	0.52	0.07	0.23
CAISO	177.97	180.76	228.00	173.24	176.86	219.99	4.73	3.90	8.01

Table 4-27 Thermal Start Cost (mill$/year) and Thermal Start Cost Reduction (mill$/year) with High RPS and Base Gas Price

4.8.3 Swan Lake PSH's Impact to Thermal Generator Ramp Up Mileages

This sub-section presents the Swan Lake PSH's impact to the thermal generator ramp up mileages in different cases.

4.8.3.1 Swan Lake PSH's Impact to Thermal Ramp up Mileages in Case of Base RPS and Base Gas Price

The following chart shows the thermal generator ramp up mileages without and with Swan Lake PSH or LMS100 in the case of base RPS and base gas price. With Swan Lake PSH, the thermal generator ramp up mileages in the focused regions is reduced by 396 GW per year (=11,648 – 11,252) or 3.4% of total ramp up mileages from the RT simulation. With 400 MW of LMS100, the thermal generator ramp up mileages is reduced by 22 GW per year (=11,648 – 11,626) or 0.2% of total ramp up mileages from the RT simulation.

The following table shows the thermal generators ramp up mileages without and with Swan Lake PSH or LMS100 for the major BAs in the focused regions. With Swan Lake PSH, the thermal generator ramp up mileages is reduced by 235 GW per year or 3.3% of total ramp up mileages in CAISO from the RT simulation (under columns of "Swan Lake – Base"), i.e., CAISO is the major beneficiary of Swan Lak PSH.

With 400 MW of LMS100, the thermal generator ramp up mileages is reduced by 147 GW per year in CAISO from the RT simulation (under columns of "LMS100 – Base"). However, in some major BAs, the generator ramp up mileages is increased. Therefore the bi-directional thermal generator ramp up mileage changes by BA may not reflect the true BA thermal generator ramp up mileage reduction by LMS100.

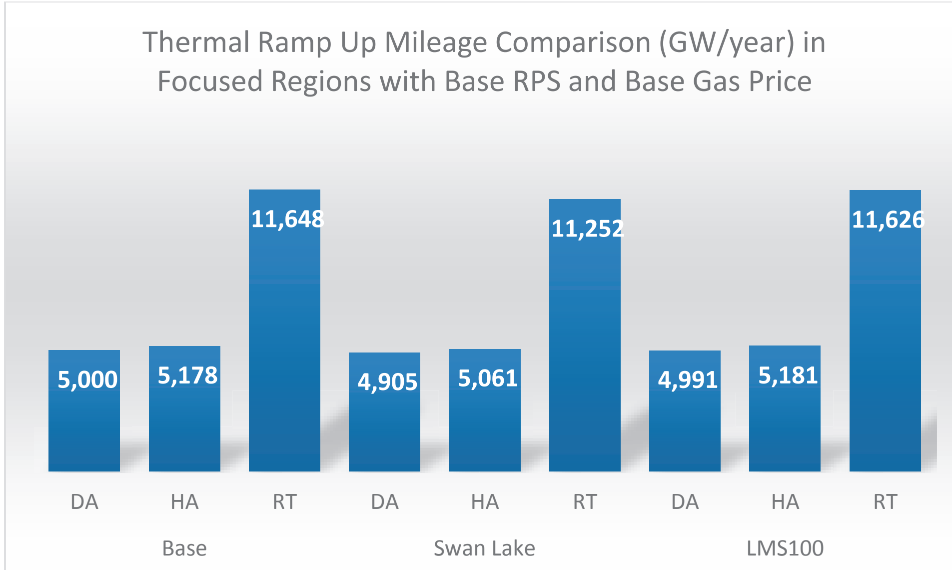

Figure 4-16 Thermal Ramp Up Mileage Comparison (GW/year) in Focused Regions with Base RPS and Base Gas Price

Thermal Ramp Up Mileage (GW/year) and Thermal Ramp Up Mileage Reduction (GW/year) with Base RPS and Base Gas Price															
	Thermal Ramp Up Mileage (GW/year)									Thermal Ramp Up Mileage Reduction (GW/year)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	5,000	5,178	11,648	4,905	5,061	11,252	4,991	5,181	11,626	95	117	397	9	(2)	22
PacifiCorp	241	242	473	228	231	455	240	242	468	12	10	18	1	(0)	5
PGE	61	66	139	58	61	131	60	64	139	2	5	7	0	1	(0)
Avista Corp	43	49	78	40	46	71	43	47	75	2	3	7	(0)	2	4
Puget Sound	172	166	347	166	160	328	173	166	343	5	6	19	(1)	0	4
PG&E	1,167	1,195	2,824	1,142	1,168	2,695	1,162	1,196	2,750	25	27	130	5	(1)	74

SDG&E	481	529	1,272	477	523	1,247	476	530	1,264	4	7	25	5	(0)	8
SCE	1,377	1,336	3,342	1,363	1,318	3,262	1,362	1,329	3,278	14	18	80	15	8	64
LADWP	261	294	600	258	286	576	263	290	589	4	8	24	(1)	4	11
SMUD	278	261	461	276	256	444	279	261	451	2	5	17	(1)	(0)	11
BPA	361	391	817	344	371	770	378	407	1,002	17	20	48	(17)	(15)	(185)
CAISO	3,024	3,061	7,438	2,982	3,009	7,203	3,000	3,055	7,292	42	51	235	24	6	147

Table 4-28 Thermal Ramp Up Mileage (GW/year) and Thermal Ramp Up Mileage Reduction (GW/year) with Base RPS and Base Gas Price

4.8.3.2 Swan Lake PSH's Impact to Thermal Ramp up Mileages in Case of Base RPS and High Gas Price

The following chart shows the thermal generator ramp up mileages without and with Swan Lake PSH or LMS100 in the case of base RPS and high gas price. With Swan Lake PSH, the thermal generator ramp up mileages in the focused regions is reduced by 370 GW per year (=11,371 – 11,001) or 3.3% from the RT simulation. With 400 MW of LMS100, the thermal generator ramp up mileages is reduced by 53 GW per year (=11,371 – 11,318) or 0.3% from the RT simulation.

The following table shows the thermal generators ramp up mileages without and with Swan Lake PSH or LMS100 for the major BAs in the focused regions. With Swan Lake PSH, the thermal generator ramp up mileages is reduced by 200 GW per year or 2.8% of total ramp up mileages in CAISO from the RT simulation (under columns of "Swan Lake – Base"), i.e., CAISO is the major beneficiary of Swan Lak PSH.

With 400 MW of LMS100, the thermal generator ramp up mileages is reduced by 157 GW per year in CAISO from the RT simulation (under columns of "LMS100 – Base"). However, in some major BAs, the generator ramp up mileages is increased. Therefore the bi-directional thermal generator ramp up mileage changes by BA may not reflect the true BA thermal generator ramp up mileage reduction by LMS100.

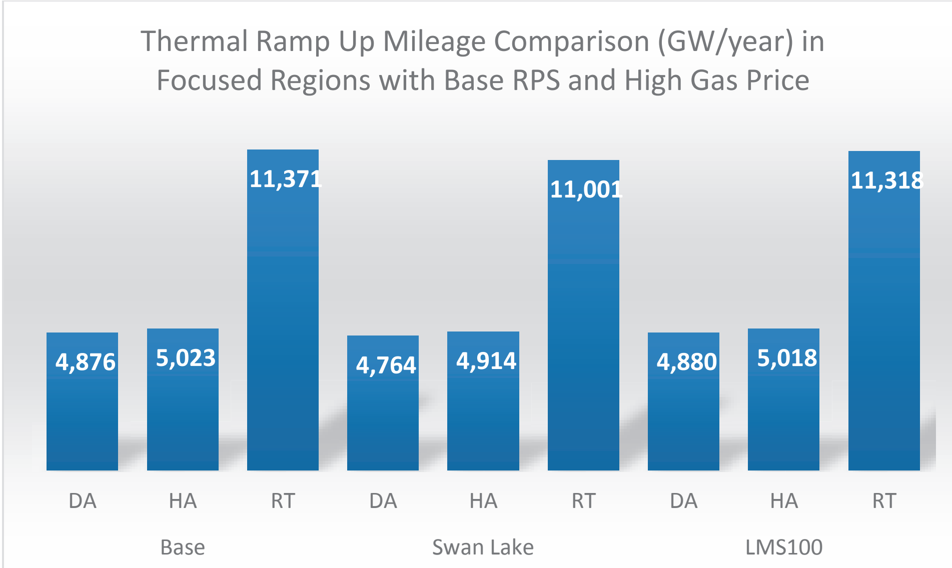

Figure 4-17 Thermal Ramp Up Mileage Comparison (GW/year) in Focused Regions with Base RPS and High Gas Price

Thermal Ramp Up Mileage (GW/year) and Thermal Ramp Up Mileage Reduction (GW/year) with Base RPS and High Gas Price															
	Thermal Ramp Up Mileage (GW/year)									Thermal Ramp Up Mileage Reduction (GW/year)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	4,876	5,023	11,371	4,764	4,914	11,001	4,880	5,018	11,318	113	109	369	(3)	5	53
PacifiCorp	227	226	446	217	218	423	229	226	442	10	8	23	(2)	1	5
PGE	56	59	128	54	56	121	56	58	126	2	3	7	0	1	2
Avista Corp	45	51	81	42	48	77	45	50	78	3	3	4	(0)	1	2
Puget Sound	156	150	311	151	145	298	155	148	308	5	5	13	1	2	3
PG&E	1,151	1,170	2,708	1,119	1,136	2,586	1,146	1,167	2,632	33	33	122	6	2	75

SDG&E	475	518	1,259	463	510	1,237	472	516	1,246	12	9	22	2	2	14
SCE	1,353	1,306	3,349	1,335	1,293	3,293	1,344	1,296	3,281	18	12	57	9	9	68
LADWP	264	289	603	262	283	573	264	289	592	1	6	30	(1)	(0)	11
SMUD	263	254	440	260	250	424	265	255	432	3	4	16	(2)	(1)	8
BPA	354	384	789	338	364	737	374	401	956	16	19	52	(20)	(17)	(167)
CAISO	2,979	2,994	7,316	2,917	2,940	7,116	2,963	2,980	7,159	63	54	200	17	14	157

Table 4-29 Thermal Ramp Up Mileage (GW/year) and Thermal Ramp Up Mileage Reduction (GW/year) with Base RPS and High Gas Price

4.8.3.3 Swan Lake PSH's Impact to Thermal Ramp up Mileages in Case of High RPS and Base Gas Price

The following chart shows the thermal generator ramp up mileages without and with Swan Lake PSH in the case of high RPS and base gas price. With Swan Lake PSH, the thermal generator ramp up mileages in the focused regions is reduced by 353 GW per year (=11,718 – 11,365) or 3.0% from the RT simulation.

The following table shows the thermal generators ramp up mileages without and with Swan Lake PSH for the major BAs in the focused regions. With Swan Lake PSH, the thermal generator ramp up mileages is reduced by 198 GW per year or 2.8% of total ramp up mileages in CAISO from the RT simulation (under columns of "Swan Lake – Base"), i.e., CAISO is the major beneficiary of Swan Lake PSH.

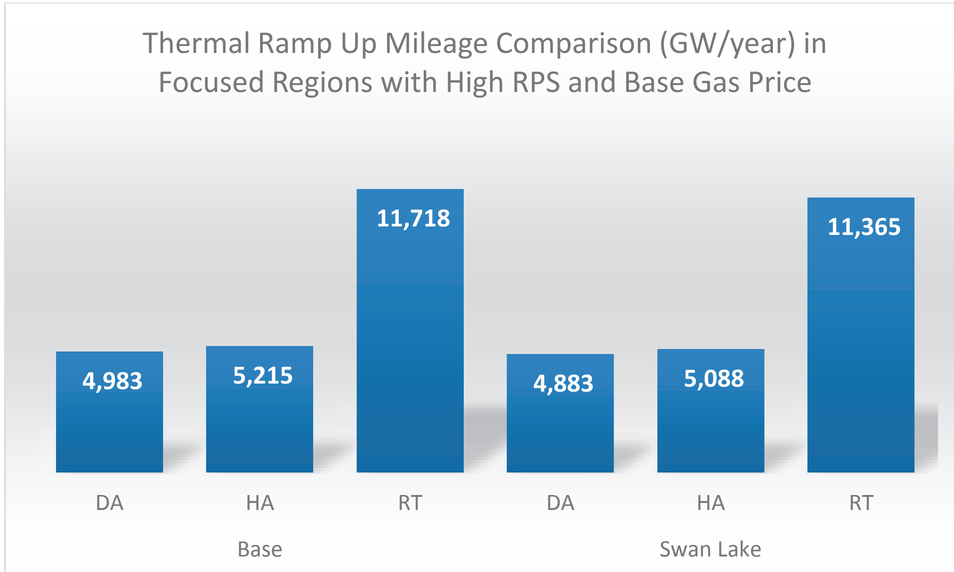

Figure 4-18 Thermal Ramp Up Mileage Comparison (GW/year) in Focused Regions with High RPS and Base Gas Price

Thermal Ramp Up Mileage (GW/year) and Thermal Ramp Up Mileage Reduction (GW/year) with High RPS and Base Gas Price									
	Thermal Ramp Up Mileage (GW/year)						Thermal Ramp Up Mileage Reduction (GW/year)		
Evaluated Resource	Base			Swan Lake			Swan Lake - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	4,983	5,215	11,718	4,883	5,088	11,001	101	127	353
PacifiCorp	246	249	465	233	240	423	12	9	10

PGE	60	64	134	58	61	121	2	3	6
Avista Corp	41	45	79	38	43	77	3	2	6
Puget Sound	177	175	354	171	167	298	6	8	14
PG&E	1,116	1,169	2,739	1,092	1,136	2,586	24	33	109
SDG&E	498	554	1,209	496	544	1,237	2	11	22
SCE	1,371	1,328	3,507	1,349	1,311	3,293	22	17	67
LADWP	294	322	631	295	316	573	(1)	5	15
SMUD	267	258	446	262	253	424	4	5	17
BPA	366	403	795	348	383	737	18	20	24
CAISO	2,984	3,051	7,455	2,937	2,990	7,116	48	61	198

Table 4-30 Thermal Ramp Up Mileage (GW/year) and Thermal Ramp Up Mileage Reduction (GW/year) with High RPS and Base Gas Price

4.8.4 Swan Lake PSH's Impact to Thermal Generator Ramp Down Mileages

This sub-section presents the Swan Lake PSH's impact to the thermal generator ramp down mileages in different cases.

4.8.4.1 Swan Lake PSH's Impact to Thermal Ramp Down Mileages in Case of Base RPS and Base Gas Price

The following chart shows the thermal generator ramp down mileages without and with Swan Lake PSH or LMS100 in the case of base RPS and base gas price. With Swan Lake PSH, the thermal generator ramp down mileages in the focused regions is reduced by 437 GW per year (=13,359 – 12,922) or 3.3% of total ramp down mileages from the RT simulation. With 400 MW of LMS100, the thermal generator ramp down mileages is reduced by -27 GW per year (=13,359 – 13,386) or -0.2% from the RT simulation.

The following table shows the thermal generators ramp down mileages without and with Swan Lake PSH or LMS100 for the major BAs in the focused regions. With Swan Lake PSH, the thermal generator ramp down mileages is reduced by 263 GW per year or 3.2% of total ramp down mileages in CAISO from the RT simulation (under columns of "Swan Lake – Base"), i.e., CAISO is the major beneficiary of Swan Lak PSH.

With 400 MW of LMS100, the thermal generator ramp down mileages is reduced by 149 GW per year in CAISO from the RT simulation (under columns of "LMS100 – Base"). However, in some major BAs, the generator ramp down mileages is increased. Therefore the bi-directional thermal generator ramp down mileage changes by BA may not reflect the true BA thermal generator ramp down mileage reduction by LMS100.

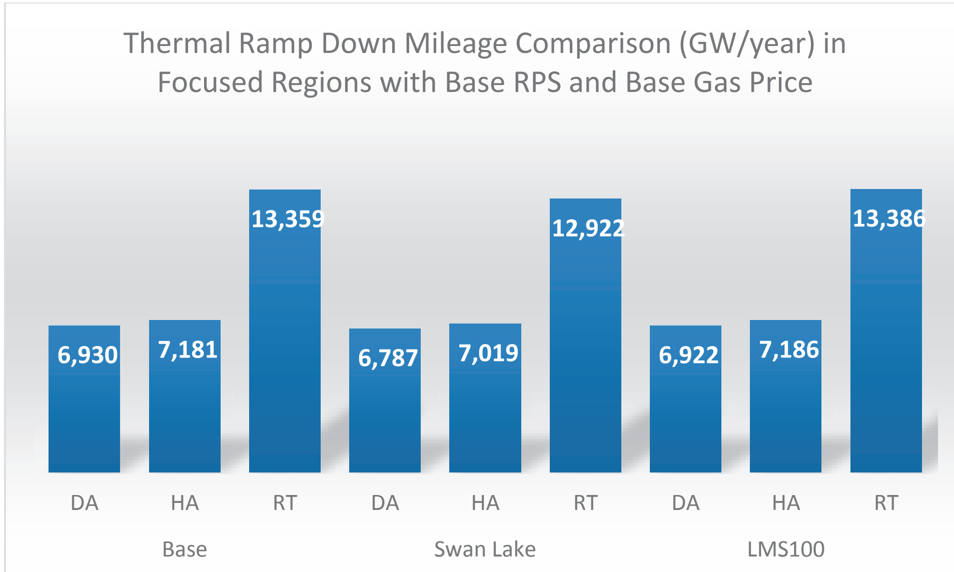

Figure 4-19 Thermal Ramp Down Mileage Comparison (GW/year) in Focused Regions with Base RPS and Base Gas Price

Thermal Ramp Down Mileage (GW/year) and Thermal Ramp Down Mileage Reduction (GW/year) with Base RPS and Base Gas Price															
	Thermal Ramp Down Mileage (GW/year)									Thermal Ramp Down Mileage Reduction (GW/year)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	6,930	7,181	13,359	6,787	7,019	12,922	6,922	7,186	13,386	143	162	436	8	(5)	(27)
PacifiCorp	252	252	481	239	242	464	250	252	476	13	11	18	1	(0)	5
PGE	66	76	149	63	70	140	65	74	149	3	6	8	1	1	(0)
Avista Corp	61	69	93	58	66	85	62	67	88	3	3	7	(0)	3	5
Puget Sound	179	173	352	174	167	333	180	173	348	6	6	19	(1)	0	4
PG&E	1,577	1,607	3,247	1,538	1,569	3,102	1,573	1,607	3,170	39	39	144	5	0	76

SDG&E	627	686	1,406	622	677	1,378	622	685	1,396	5	8	28	5	0	10
SCE	2,103	2,040	3,833	2,071	2,007	3,743	2,079	2,032	3,770	32	33	90	24	9	63
LADWP	351	390	704	344	379	675	352	386	687	8	11	29	(1)	4	16
SMUD	346	314	510	342	309	494	346	314	500	3	4	16	(1)	(0)	11
BPA	432	478	895	409	452	845	462	504	1,141	22	26	51	(30)	(26)	(245)
CAISO	4,307	4,333	8,486	4,231	4,253	8,224	4,274	4,324	8,337	76	80	263	33	9	149

Table 4-31 Thermal Ramp Down Mileage (GW/year) and Thermal Ramp Down Mileage Reduction (GW/year) with Base RPS and Base Gas Price

4.8.4.2 Swan Lake PSH's Impact to Thermal Ramp Down Mileages in Case of Base RPS and High Gas Price

The following chart shows the thermal generator ramp down mileages without and with Swan Lake PSH or LMS100 in the case of base RPS and High gas price. With Swan Lake PSH, the thermal generator ramp down mileages in the focused regions is reduced by 417 GW per year (=13,129 – 12,712) or 3.2% of total ramp down mileages from the RT simulation. With 400 MW of LMS100, the thermal generator ramp down mileages is reduced by 14 GW per year (=13,129 – 13,115) or 0.1% from the RT simulation.

The following table shows the thermal generators ramp down mileages without and with Swan Lake PSH or LMS100 for the major BAs in the focused regions. With Swan Lake PSH, the thermal generator ramp down mileages is reduced by 238 GW per year or 2.9% of total ramp down mileages in CAISO from the RT simulation (under columns of "Swan Lake – Base"), i.e., CAISO is the major beneficiary of Swan Lake PSH.

With 400 MW of LMS100, the thermal generator ramp down mileages is reduced by 171 GW per year in CAISO from the RT simulation (under columns of "LMS100 – Base"). However, in some major BAs, the generator ramp down mileages is increased. Therefore the bi-directional thermal generator ramp down mileage changes by BA may not reflect the true BA thermal generator ramp down mileage reduction by LMS100.

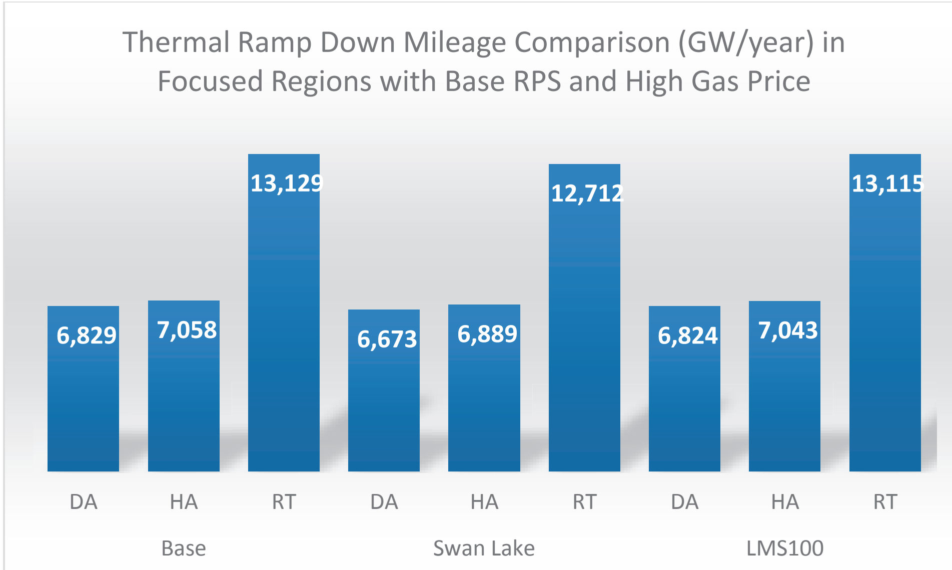

Figure 4-20 Thermal Ramp Down Mileage Comparison (GW/year) in Focused Regions with Base RPS and High Gas Price

Thermal Ramp Down Mileage (GW/year) and Thermal Ramp Down Mileage Reduction (GW/year) with Base RPS and High Gas Price															
	Thermal Ramp Down Mileage (GW/year)									Thermal Ramp Down Mileage Reduction (GW/year)					
Evaluated Resource	Base			Swan Lake			LMS100			Swan Lake - Base			LMS100 - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	6,829	7,058	13,129	6,673	6,889	12,712	6,824	7,043	13,115	155	169	417	5	15	14
PacifiCorp	238	236	454	228	229	431	240	236	450	10	8	23	(2)	0	4
PGE	62	69	138	60	65	130	62	66	135	2	4	7	0	2	3
Avista Corp	64	72	96	60	69	92	63	70	93	4	3	4	0	2	3
Puget Sound	163	157	316	159	152	303	162	155	313	5	5	13	1	2	3
PG&E	1,579	1,613	3,157	1,529	1,556	3,014	1,567	1,598	3,071	50	58	142	13	15	86

SDG&E	626	679	1,397	612	668	1,373	621	677	1,383	14	11	24	4	3	14
SCE	2,084	2,009	3,854	2,048	1,974	3,782	2,064	1,995	3,782	36	35	71	20	14	71
LADWP	358	383	706	356	375	673	357	383	692	2	7	33	0	0	14
SMUD	331	309	490	329	304	475	333	310	483	2	4	16	(2)	(1)	8
BPA	424	469	866	406	446	811	459	499	1,093	19	23	56	(34)	(30)	(227)
CAISO	4,289	4,301	8,407	4,189	4,197	8,170	4,252	4,270	8,236	100	104	238	37	32	171

Table 4-32 Thermal Ramp Down Mileage (GW/year) and Thermal Ramp Down Mileage Reduction (GW/year) with Base RPS and High Gas Price

4.8.4.3 Swan Lake PSH's Impact to Thermal Ramp Down Mileages in Case of High RPS and Base Gas Price

The following chart shows the thermal generator ramp down mileages without and with Swan Lake PSH in the case of High RPS and base gas price. With Swan Lake PSH, the thermal generator ramp down mileages in the focused regions is reduced by 391 GW per year (=13,514 – 13,123) or 2.9% of total ramp down mileages from the RT simulation.

The following table shows the thermal generators ramp down mileages without and with Swan Lake PSH for the major BAs in the focused regions. With Swan Lake PSH, the thermal generator ramp down mileages is reduced by 220 GW per year or 2.4% of total ramp down mileages in CAISO from the RT simulation (under columns of "Swan Lake – Base"), i.e., CAISO is the major beneficiary of Swan Lake PSH.

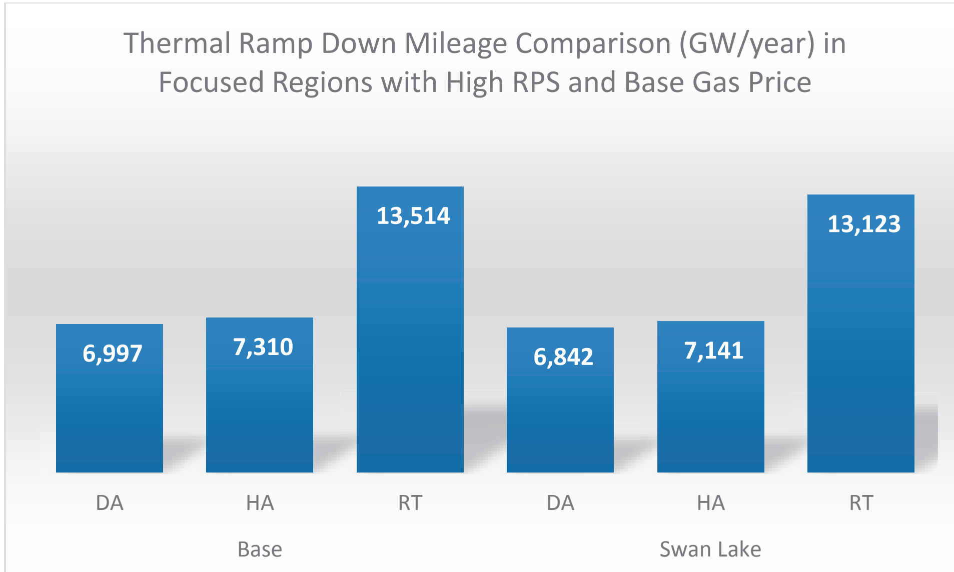

Figure 4-21 Thermal Ramp Down Mileage Comparison (GW/year) in Focused Regions with High RPS and Base Gas Price

Thermal Ramp Down Mileage (GW/year) and Thermal Ramp Down Mileage Reduction (GW/year) with High RPS and Base Gas Price									
	Thermal Ramp Down Mileage (GW/year)						Thermal Ramp Down Mileage Reduction (GW/year)		
Evaluated Resource	Base			Swan Lake			Swan Lake - Base		
	DA	HA	RT	DA	HA	RT	DA	HA	RT
Focused Regions	6,997	7,310	13,514	6,842	7,141	13,123	155	169	390
PacifiCorp	257	259	474	244	250	464	12	9	10
PGE	65	71	140	63	67	134	2	3	6
Avista Corp	56	62	90	53	60	84	3	2	6

Puget Sound	185	182	359	179	174	345	6	8	14
PG&E	1,514	1,582	3,157	1,477	1,539	3,039	37	43	118
SDG&E	660	732	1,350	658	720	1,327	2	11	22
SCE	2,167	2,094	4,049	2,120	2,061	3,969	47	33	80
LADWP	400	430	770	394	419	746	6	11	25
SMUD	341	318	502	336	312	485	5	6	18
BPA	426	475	858	404	454	834	22	21	24
CAISO	4,341	4,407	8,556	4,255	4,320	8,336	86	88	220

Table 4-33 Thermal Ramp Down Mileage (GW/year) and Thermal Ramp Down Mileage Reduction (GW/year) with High RPS and Base Gas Price

5 Findings

The findings from the simulation result analyses are listed as follows in year 2022 dollar.

5.1 Production Cost Savings in Focused Regions

With Swan Lake PSH, the focused region production cost reductions from the RT simulations are listed in the following table.

Comparison of the Production Cost Reduction in Focused Regions and CAISO from 5-min RT Simulations (million $)			
Case	**Base RPS and Base Gas Price**	**Base RPS and High Gas Price**	**High RPS and Base Gas Price**
Focused Regions	$36	$37	$52
CAISO	$26	$28	$33

Table 5-1 Comparison of the Production Cost Reduction in Focused Regions and CAISO from 5-min RT Simulations

It is obvious that CAISO benefits most from Swan Lake PSH.

The production cost reduction from 400MW of LMS100 are only in the range of 4 to 11 million $ in the focused regions by comparison.

The 3-stage sequential simulation solutions show that the production costs from the 5-min RT simulation are much higher than that from the DA simulation due to the generator cycling to cover the 5-min load and renewable uncertainty and variability in the 5-min RT operation. The following table shows the production cost comparison between the DA simulations and the 5-min simulations. The production cost from the 5-min RT simulations is about 5~7% higher than that from the DA simulations.

Comparison of Production Cost from DA Simulations and 5-min RT Simulations						
	Base RPS and Base Gas Price		**Base RPS and Base Gas Price**		**Base RPS and Base Gas Price**	
	Base	**Swan Lake**	**Base**	**Swan Lake**	**Base**	**Swan Lake**
DA Production Cost (mill$)	6,294	6,276	6,791	6,777	5,909	5,883
RT Production Cost (mill$)	6,604	6,568	7,124	7,087	6,317	6,263
Difference (RT - DA) (mill$)	310	292	333	310	408	380
% of Diff (RT - DA)/DA	5%	5%	5%	5%	7%	6%

Table 5-2 Comparison of Production Cost from DA Simulations and 5-min RT Simulations

5.2 Swan Lake PSH Operation Performance

If Swan Lake PSH is operated as an independent power producer, it will receive the energy and AS revenue at the LMP and AS price, and will pay the pumping energy cost at the LMP. The net revenue is the energy and AS revenue less the pumping cost. The following table shows the Swan Lake PSH capacity factor and net revenue from the 5-min RT simulations.

Comparison of Swan Lake PSH Capacity Factor, Net Revenue, and Capacity Value from 5-min RT Simulations			
Case	Base RPS and Base Gas Price	Base RPS and High Gas Price	High RPS and Base Gas Price
Capacity Factor (%)	33	32	35
Net Revenue (mill$)	39	41	53
Capacity Value ($/kW-Year)	100	105	136

Table 5-3 Comparison of Swan Lake PSH Capacity Factor, Net Revenue, and Capacity Value from 5-min RT Simulations

As a comparison, the capacity values of 400 MW of LMS100 falls in the range of 67 to 69 $/kW-year.

5.3 *Impact to Other Generators*

With Swan Lake PSH, the generator operations are impact in the focused regions. The most impacted generator types are CC, CT, Hydro and Renewable. The following table summarizes the generation and generation cost changes (negative value = reduction, positive value = increase)

Comparison of Generation Changes and Generation Cost Changes from 5-min RT Simulations						
	Base RPS and Base Gas Price		Base RPS and High Gas Price		High RPS and Base Gas Price	
Changes	Generation (GWh)	Generation Cost (Mill$)	Generation (GWh)	Generation Cost (Mill$)	Generation (GWh)	Generation Cost (Mill$)
CC	-241	-14	-332	-21	-337	-18
CT	-326	-23	-227	-19	-427	-35
Hydro	509		471		622	
Renewable	245		226		446	

Table 5-4 Comparison of Generation Changes and Generation Cost Changes from 5-min RT Simulations

It is noticeable that Swan Lake PSH displaces the thermal generators and allows more generation from hydro and renewable mostly for the pumping energy.

5.4 *Contributions to Emission Reductions*

Swan Lake PSH also has an impact to the emission production in the focused regions. The emission production reduction in the focused regions due to Swan Lake PSH falls in the range of 170,000 to 390,000 ton.

5.5 Contribution to Renewable Generation Integration

With Swan Lake PSH, the renewable curtailments are reduced. The following table shows the summary of renewable energy curtailment reduction from the RT simulations.

Comparison of Renewable Energy Curtailment Reduction from 5-min RT Simulations				
		Base RPS and Base Gas Price	**Base RPS and High Gas Price**	**High RPS and Base Gas Price**
Focused Regions	Renewable Energy Curtailment Reduction (GWh)	199	204	403
	% of Reduction as Curtailed Renewable Energy	6.4	6.6	1.6
CAISO	Renewable Energy Curtailment Reduction (GWh)	97	96	246
	% of Reduction as Curtailed Renewable Energy	4.7	4.7	1.2

Table 5-5 Comparison of Renewable Energy Curtailment Reduction from 5-min RT Simulations

The 400 MW of LMS100 has little impact to the renewable energy curtailment reduction.

5.6 Contribution to Thermal Generation Cycling Reductions

Due to the flexibility of Swan Lake PSH, the thermal generator cycling can be reduced. The thermal generator cycling includes number of starts, start cost, ramp up and down mileages.

The following table shows the thermal generator number of starts and start cost reduction by Swan Lake PSH from the 5-min RT simulations.

Comparison of Thermal Generator Number of Starts and Start Cost Reduction from 5-min RT Simulations				
		Base RPS and Base Gas Price	**Base RPS and High Gas Price**	**High RPS and Base Gas Price**
Focused Regions	Number of Start Reduction	2,469	1,806	3,111
	% of Number of Start Reduction	4.8	3.6	5.1
	Start Cost Reduction (mill$/year)	10.66	11.04	14.09
	% of Start Cost Reduction	3.0	3.0	3.6

CAISO	Number of Start Reduction	1,711	1,297	1,867
	% of Number of Start Reduction	4.5	3.4	4.3
	Start Cost Reduction (mill$/year)	7.37	8.53	8.01
	% of Start Cost Reduction	3.6	4.0	3.6

Table 5-6 Comparison of Thermal Generator Number of Starts and Start Cost Reduction from 5-min RT Simulations

The following table summarizes the thermal generator ramp up and down mileages.

Comparison of Thermal Generator Ramp Up and Down Mileages Reduction from 5-min RT Simulations				
		Base RPS and Base Gas Price	**Base RPS and High Gas Price**	**High RPS and Base Gas Price**
Focused Regions	Ramp Up Mileages Reduction (GW/year)	396	370	353
	% of Ramp Up Mileages Reduction	3.4	3.3	3.0
	Ramp Down Mileages Reduction (GW/year)	437	417	391
	% of Ramp Down Mileages Reduction	3.3	3.2	2.9
CAISO	Ramp Up Mileages Reduction (GW/year)	235	200	198
	% of Ramp Up Mileages Reduction	3.3	2.8	2.8
	Ramp Down Mileages Reduction (GW/year)	263	238	200
	% of Ramp Down Mileages Reduction	3.2	2.9	2.4

Table 5-7 Comparison of Thermal Generator Ramp Up and Down Mileages Reduction from 5-min RT Simulations

As a comparison, the 400 MW of LMS100 has little to the thermal generator cycling.

6 References

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[6] Lew, D., Brinkman, G., Ibanez, E., Florita, A., Heaney, M., Hodge, B.-M., Hummon, M., Stark, G., King, J., Lefton, S., Kumar, N., Agan, D., Jordan, G., Venkataraman, S. (2013). *“The Western Wind and Solar Integration Study Phase 2”*, NREL/TP-5500-55588. Golden, CO: National Renewable Energy Laboratory.

[7] Nan Zhang, Tao Guo, Guangjuan Liu, “Swan Lake Pumped-Storage Facility Economic Evaluation using PLEXOS”, Project Report to EDF-RE, December 2014

7 Appendices

A. Punch list – Input Assumption Updates
B. Result spreadsheet – Outputs A D-2 2015-08-18.xlsx
C. Result spreadsheet – Outputs E-1 E-2 2015-08-18.xlsx
D. Result spreadsheet – Outputs C A0 2015-08-18.xlsx